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REPEATED FISSION OF STEM AND ROOT IN MERTENSIA MARITIMA—A STUDY IN ECOLOGICAL ANATOMY *

By ALEXANDER F. SKUTCH

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INTRODUCTION

Among the many types of "abnormalities" which have been recorded in the mode of secondary thickening of the stem and root in dicotyledonous plants, none is more striking than that which involves the division of the axis into columns or strands which are externally distinct. Fission of this character is of regular occurrence chiefly in the stems of certain highly specialized tropical lianas, and in the rhizomes and roots of a small number of herbaceous perennials. The old herbalists were long ago familiar with the split rhizomes of several plants indigenous to Europe, and as early as 1849 Irmisch (*9*) gave a description of the method of dissection of some species of gentians. Later Jost (*11*) published a paper on "Die Zerkluftungen einiger Rhizome und Wurzeln," which remains the classic work on the subject, and in which he described the occurrence of fission in a number of species belonging to six genera of European herbs. Since the appearance of Jost's paper a few cases have been added to his list, but the process of fission in *Mertensia maritima,* which exhibits a degree of complexity far exceeding any of the previously described examples, and approaching that which obtains in certain lianas as described by Schenck (*20*), has apparently never

* The publication of this paper (Botanical Contribution from the Johns Hopkins University, No. 105) has been made possible through a grant from the income of the Esther Herrman Fund of the N. Y. Academy of Sciences

received the attention which it merits. It was to supply this deficiency, and to attempt to correlate the unique anatomical features of the plant with the peculiar conditions it encounters in the shingle beaches, the habitat in which it seems to thrive best, that the present study was undertaken.

My study of *Mertensia* was begun during the summer of 1925, while working under the guidance of Professor Duncan S. Johnson at the Mount Desert Island Biological Laboratory at Bar Harbor, Maine. The investigation of the anatomical details was continued in the botanical laboratory of the Johns Hopkins University, where the writer held the James Buchanan Johnston Scholarship, and in early June, 1928, a visit was made to Mount Desert Island to observe the behavior of the plant in the field at the outset of the growing season. I desire to express my warmest gratitude to Professor Johnson for the helpful and sympathetic criticism which he has continued to give throughout the course of this work, and to him and Mr. George D. Johnson for the collection of material in the late summer of 1928, when I was unable to visit the Island.

THE PLANT AND ITS HABITAT

The sea lungwort, *Mertensia maritima* (L.) S. F. Gray is a plant of widespread occurrence on the seacoasts of high latitudes throughout the Northern Hemisphere [Gray (*6*)] * On our Atlantic Coast it pushes down as far as Nantucket Island off the coast of Massachusetts, but is not at all frequent south of Maine, whence it ranges northward to Baffin Land and the Arctic Archipelago, and extends up the west coast of Greenland at least as far as Pröven, at 72° N. latitude [Kane (*12*)]. As I know it on Mt. Desert Island, Maine, where all of the material employed in the present study was collected, it is essentially a plant of shingle beaches on the exposed shores, and I am not aware of its occurrence on the rocky, but sheltered, northern coast of the island. From other sources we find references to its presence on gravelly barrier beaches and sandy beaches in Nova Scotia [Fernald (*5*)] and on beaches of coarse sand in the Faeroës [Ostenfeld (*15*)], and taxonomic works give as its habitat both sandy and rocky shores. But the shingle beach seems to be a favored habitat; thus Carey and Oliver (*2*) record that it is one of the local rarities of Blakeney Point, Norfolk, England, where it grows on the extensive shingle deposits.

* Throughout this paper the italicized figures in parentheses refer to works, similarly designated, in the Bibliography.

The shingle beaches which are the habitat of *Mertensia* on Mt. Desert Island are of two forms—the fringing type, which lies in direct contact with the higher land behind the shore; and the bar or barrier type, which occurs as a ridge of shingle between the sea and the salt meadow, lagoon or the dammed mouth of a stream, as the case may be, which lies to the landward of it [see Carey and Oliver (*2*), Oliver (*14*)]. The largest and most vigorous plants grew on beaches of the bar type, in mobile shingle (Pl. I, fig. 1). A beach of this form along the western side of Bass Harbor is composed of small, rounded stones of gray shale, averaging about the size of a walnut, which shift with a rattling and grating sound as one walks across them. The shingle ridge rises steeply from the water's edge to the flat crest at about 5-6 feet above the mean high water level, whence it falls abruptly on the landward side to a salt meadow dominated by *Triglochin maritima* and *Myrica gale,* lying some 5-8 ft. below its summit. The plants of *Mertensia* grew principally on the level summit and on the seaward face of the ridge, where the lowest were several feet above the reach of the tides. In June, 1928, dead stems of the previous summer, lying undisturbed on the shingle beneath the new shoots of the season's growth, gave evidence that the higher plants on this bar had not been reached by the waves of this comparatively quiet body of water during the previous winter, but individuals lower down on the seaward face were mingled with dead algæ and the varied debris washed up by the billows. Even the plants on the summit, however, had during previous winters' storms been buried by the up-building shingle to the depth of over a foot since their establishment as seedlings.

Near by were a series of local beaches of the fringing type, lying between outcropping ledges of the rocky shore, and some of these had been stable for a number of years, during which the interstices between the stones had become filled with sand and fine gravel. The plants of these beaches were never half so large as the largest on the bar. Another shingle bar near Manset, composed of large, angular rocks intermixed with the smaller, rounded stones, stood in part above a *Triglochin* meadow and in part above a lagoon formed by the damming of a small, fresh-water stream (Pl. I, fig. 1). Here also *Mertensia* grew on the seaward face near the top of the beach, and the plants were larger than any found on the extensive reaches of fringing shingle beach near by.

The characteristics of the shingle beach as a plant habitat have been considered in several papers by Oliver and his students (*8, 14*). By themselves, the rounded stones washed up by the waves to form a bar or

a fringing beach would constitute a very poor habitat for vascular plants of any sort, but in the beaches on which *Mertensia* is established all but the most superficial layers of shingle contain a greater or less accumulation of soil. This consists of sand and fine gravel, either washed up by the waves or ground off the larger stones, calcareous matter derived from shells which are washed into the shingle and usually ground into fine pieces by the attrition of the larger stones, and finally of a quite considerable amount of organic material derived from flotsam of every conceivable sort deposited on the beach (Pl. II, fig. 4). The latter is made up principally of seaweeds, but contains also much wood and a certain amount of animal remains. When the beach is of the fringing type, its soil content may be augmented by material eroded from the land behind it, but in the case of bars, practically everything must be derived from the wash of the sea. Carey and Oliver (*2*) and Hill and Hanley (*8*) have considered the water content of shingle beaches. They record that these always contain an abundance of fresh soil water, even when meadows and woods inland to them are parched from a prolonged drought. Although, in certain cases at least, the water supply of a fringing beach may be augmented by run-off and seepage from the land, or by capillary rise from a fresh water table beneath it, it is evident that the shingle bar, standing as it does above the surface of the land or water behind it, is entirely cut off from such sources of moisture. The most obvious manner in which it receives fresh water is by rainfall and dew formation, but apparently these sources are not sufficient in all cases to account for the liberal supply usually present. Oliver (*14*) makes the interesting suggestion that fresh water may be added to the superficial layers of the beach by distillation from the sea water which penetrates beneath it, or, as he terms it, by "internal dew formation."

When a seedling of *Mertensia,* surviving the great odds against establishment in the inhospitable habitat we have just described, becomes firmly rooted, the hypocotyl and the upper portion of the primary root thicken into a fleshy, spindle-shaped tap-root, while a rosette of leaves develops above the cotyledonary node (Pl. III, fig. 5). In the second summer of the plant's existence one or, more often, several aerial flowering shoots grow out from the axillary buds at the crown of the tap-root and lie along the surface of the shingle. These aerial shoots, which are usually unbranched, die back to the tap-root in the fall, but in each succeeding spring a still larger number of more vigorous shoots grow out from the buds at the crown of the perennating hypocotyl, and lie on the shingle radiating in all directions from the original point of establish-

ment of the plant (Pl. I, fig. 1; Pl. II, fig. 3). The foliage of these decumbent shoots stands above the stems on short, ill-defined petioles; the ovate, obovate or spatulate leaves are covered with a thick waxy bloom, which imparts a striking glaucous color to the low and spreading mass of herbage each large plant produces; the delicate blue flowers, produced in July and August, are borne on short, ascending peduncles. The number of buds at the crown increases from year to year, until in a few seasons they form a thick, swollen mass, some of which each year give rise to the current flowering shoots. Meanwhile the tap-root has thickened considerably, and has become divided, in the manner which is described in detail below, into a large number of anastomosing strands (Pl. III, fig. 6; Pl. VII, fig. 13; Pl. VIII, fig. 15), each of which is divided anew at the outset of every growing season. The root system consists of a rather restricted number of thick, fleshy roots and their finer laterals (Pl. I, fig. 2). The lateral roots run horizontally through the shingle for considerable distances and one was traced for a length of 90 centimeters from the tap-root. They thicken and become split longitudinally in a fashion very similar to the tap-rot.

Still more interesting and complex are the life history and structure of a plant which grows in a shingle beach the level of which has been raised since the establishment of the individual. In the spring of 1928, I found plants which in three winters had been buried to the depth of 40 cm. (Pl. IV, fig. 7). All of the largest plants which I found on Mt. Desert Island had been buried more or less deeply by accretions of shingle since their germination. The violent surf which shifts the shingle at the levels where *Mertensia* is established is usually the product of the winter storms. In the following spring some of the buds at the crown of the tap-root (if it is a plant which has been buried for the first time) break their dormancy and push up through the overlying debris of shingle, and the decaying flotsam and jetsam which has been incorporated with it, as slender, etiolated shoots, much contorted from their sinuous passage between the stones (Pl. II, fig. 4; Pl. VII, fig. 14). Having emerged from the shingle, they continue to grow over it as green, leafy shots of normal appearance. While the aerial portions of such stems die off in winter, the buried portions, differing greatly from the former in internal organization, survive the cold months and constitute an addition to the perennating portion of the plant. In the succeeding spring the lateral buds of the subterranean length of the shoot give rise to the flowering shoots, while the buried axis becomes dissected into strands in a manner somewhat similar to the hypocotyl and roots. Other

shoots may still arise from the crown of the tap-root, even at a depth of 40 cm. beneath the surface. At the beginning of the second season's activity each strand is again divided into several strands of a higher order. The dormant buds at the nodes increase in number until the groups of them form great swellings, at which the strands, separate from each other in the intervening stretches of the stem, are bound together by vascular anastomoses.

Thus the subterranean, perennating portion of a large, old plant becomes a thing of bewildering complexity. Such a plant, found growing on the bar at Bass Harbor in August, 1925, was the most impressive specimen which I unearthed (Pl. VIII, fig. 16). The lowest mass of dormant buds, 30 cm. beneath the surface, indicated the crown of the tap-root and the original level of the shingle, which had been built up 30 cm. since the establishment of the seedling. The tap-root had disintegrated into a large number of rather slender, anastomosing strands. From this arose lateral roots, the largest of which had become divided into a thick, cable-like bundle of spirally twisted strands (Pl. V, fig. 9). Because of the great difficulty of digging in the shifting shingle, which to one's great exasperation rolled into the excavation almost as rapidly as it could be removed, it was not possible to expose the whole root system of the plant. From the crown of the tap-root, which was 7 cm. in diameter, the dissected perennial stems arose in a tangled cluster, which expanded to twice that diameter 30 cm. higher up, at the surface of the beach. Shells and small, rounded stones were impacted in the mass of stranded stems. From the mode of branching of these stems it seems probable that the shingle had been piled up over the plant during several different winters, and not all in a single period of dormancy. From the top of this inverted cone of perennial branches arose the annual flowering stems of the season's growth. There were 117 of them which, lying prone over the shingle, completely covered it over a circle 180 cm. in diameter. This plant was at least four years old, and probably not more than five, although the exact age of such a large plant is not so easy to determine as that of a younger specimen. Another large plant, growing near by, consisted of 266 flowering stems, which covered a circle 210 cm. in diameter.

Although the formation of such an extensive but still subterranean superstructure above the tap-root provides a larger base for the support of a great quantity of the annual flowering shoots, plants which have not been deeply buried produce a surprisingly large number of them. Thus a specimen found near Manset, which consisted of 260 flowering

stems, covering a circle of 120 cm. in diameter in early June, while they were still elongating vigorously, had been buried to a depth of only 8 cm. (this is the plant shown in Pl. I, fig. 2; Pl. II, fig. 3). The flattened hypocotyl of this plant was 7 cm. by 4 cm. in diameter. On the other hand, plants growing in quieter shingle, which had not been built up at all since their establishment, but had been filled in with sand and finer gravel, in my experience always bore a considerably smaller number of flowering shoots.

Plants of the shingle beach are subjected not only to burial by the building up of the shingle, but frequently the process is reversed and the waves, lashed up by the winter storms, wash away the stones which surround them. A plant of *Mertensia* which since its establishment had not been covered by the upbuilding of the beach would probably succumb to any considerable exposure through the removal of the surrounding shingle. I have found no actual instance of the exposure of such a plant, but there is no indication that the partially uncovered roots would regenerate shoots and so perpetuate the individual. On the other hand, a plant which has previously been buried, and has formed a superstructure of perennating shoots above the tap-root, is well fitted to survive a subsequent uncovering, at least as far as the crown. All of the cauline portion of the plant is provided with numerous dormant buds and, when the more apical of these have been destroyed, those basally situated grow out to form the flowering shoots of the following season (Pl. IV, fig. 8).

Although, except for summer storms of unusual severity, *Mertensia* does not come into contact with salt water during its growing season, the young shoots are not injured when both they and the roots beneath them are subjected to a drenching of salt-water. Carey and Oliver (*2*) point out that the green shoots of the majority of the species commonly found on shingle in the British Isles suffer greatly from the contact of sea water, though a few others, such as *Glaucium luteum,* are not injured by it.

THE SEEDLING

In 1928, seedlings were first found on June 3. Most of them had not yet produced any leaves above the cotyledons, and the germination of the seeds had evidently been quite recent. The cotyledons are epigaeous, as is general in the Boraginaceæ [Jodin (*10*)]. They are spatulate in outline, about 25 mm. long by 5 mm. broad in vigorous seedlings, and borne at the end of a usually slender hypocotyl, which narrows abruptly at the base, where it joins the thread-like primary root, from which

few lateral rootlets arise. The establishment of the seedlings among the loose stones of the shingle beach is fraught with great difficulty, and the early life of the plant is indeed precarious. The seeds ripen at the end of the summer. During the winter those that are not washed completely away are mixed by the waves among the superficial layers of the shingle, and many are no doubt very deeply buried. Those shed so high on the beach that they escape the winter's waves may fall or be washed by the rain deep into the interstices of the shingle. One way or another, the advent of spring finds numbers of them at a considerable distance from the surface, and indeed at the very surface on most parts of the beach they would find little but rounded stones in which to strike root.

The dimness or absence of light from the crevices in which they start their growth produces in these seedlings the typical aspect of etiolation, with small cotyledons, short root and an enormously elongated hypocotyl. Many germinate beneath stones and produce a long, twisted, exceedingly slender hypocotyl which never succeeds in pushing into the light, and on digging in favorable localities one finds many more, hopelessly buried beneath the surface of a beach that has been raised during the past winter. The longest hypocotyl measured was 125 mm. in length, although only about 0.75 mm. in diameter. The average length of nineteen others selected at random was 81 mm. and of these six were over 100 mm. long. Jodin states of the European Boraginaceæ, of which he studied numerous species, that the hypocotyl is almost always more than 15 mm. and rarely so much as 50 mm. long. The hypocotyls of these light-starved seedlings of *Mertensia* are so delicate that it is almost impossible to handle them without their breaking (see Pl. VI, fig. 12). That the long hypocotyl so commonly found is an expression of the environmental conditions under which germination occurs, rather than of the genetic constitution of the plant, is attested by the fact that the most advanced seedlings have the shortest hypocotyls. Thus the most advanced seedling found on June 3 had a hypocotyl only 37 mm. long, while the primary root measured 45 mm. The production of long, slender hypocotyls in response to environmental conditions is apparently a general characteristic of plants growing in the shingle.

A seedling arising from a larger seed containing a greater reserve of food would experience less difficulty in striking root and reaching the light, but the seeds of *Mertensia,* as is characteristic of the more familiar members of its family, are small, and many of the delicate spindling seedlings which issue from them exhaust all of their reserves in an effort to reach the light, only to perish because they have not at the same time

been able to produce an efficient root system in the gravelly interstices of the shingle. In this respect *Mertensia* is very poorly adapted to its environment. In the afternoon of a bright day one finds many seedlings lying limp and dying against the stones between which they have pushed. The mortality of the seedlings is enormous, and when one adds to this the number of seeds washed away or deeply buried by the waves, it can readily be understood why the plants of *Mertensia* are so scattered, and rarely form a close stand on the beach (Pl. I, fig. 1).

Beneath the cotyledons the stele of the hypocotyl contains two collateral bundles with a central pith. The transition of the stele to the radical type takes place in the upper portion of the hypocotyl, and the pith has usually disappeared at about one-quarter the length of the hypocotyl below the cotyledons. The lower portion of the hypocotyl and the primary root are exarch and diarch. The xylem rays, each of which consists of usually two or three elements of protoxylem and one of metaxylem, meet in the center, and so a xylem plate with two poles is formed. Although the number of elements in the rays is accordingly very small, additional metaxylem elements had differentiated beside the rays even in the youngest seedlings examined. In the upper portion of the hypocotyl the stele is limited by an endodermis of the cauline type, with a very narrow Casparian band (Fig. 23) while in its lower portion, as in the root, the Casparian band is broad and covers almost the entire radial wall of the endodermal cell. The lateral roots possess the same primary stelar structure as the primary root. The anatomy of the seedling of *Mertensia* conforms closely to the general Boraginaceous type as described by Jodin.

ANATOMY AND EARLY FISSION OF THE HYPOCOTYL AND ROOT

Soon after the commencement of secondary thickening in the hypocotyl of the seedling, a phellogen arises in the outermost layer of the pericycle. When this occurs, it can be demonstrated that the endodermis has gone over into the "secondary stage," as characterized by Priestley and North (*19*). The walls, in addition to the Casparian strip, stain yellow instead of blue with chloroiodide of zinc, and persist as a very delicate membrane after the treatment of sections with concentrated sulfuric acid. The activity of the phellogen in the hypocotyl and root is limited, and at the time the development of the periderm is completed it consists of usually two or three layers of cork, and one or two of phelloderm, separated by a single, inactive phellogen cell. With the formation of the periderm, the

primary cortex dies and is sloughed off. The secondary xylem consists only of tracheæ and unlignified parenchyma. The vessels are reticulately thickened (Fig. 7), the pits are simple, and the ends of the vessel segments are completely open. The parenchyma cells, when examined in radial sections, lie in well-defined horizontal series, for each one retains the length of the cambial cell from which it was derived, and the end walls maintain a regular alignment. The individual segments of the vessels, where these occur, fall into the series of longitudinally elongated parenchyma cells. The secondary phloem consists of sieve-tubes, which occur together in little groups of usually three to five, although many are found singly, their companion cells and parenchyma indistinguishable from that of the xylem. The sieve-plates, which fall into line with the ends of the parenchyma cells of the same series in which the sieve-tube lies, are transverse. The walls of the sieve-tubes are slightly thickened, so that in section they stand out from the surrounding parenchyma.

Coincident with the increase in diameter of the organ, the parenchyma cells of the outer portion of the secondary cortex become tangentially elongated and divide by radial walls. Transverse walls are also formed at this time, and so the alignment of cells, so distinct in both transverse and radial sections of the younger portions of the phloem, is destroyed. The sieve-tubes about half-way across the secondary cortex from the cambium have by the end of August become clogged by the formation of thick pads of callose across their sieve-plates.

The distribution of these elements of xylem and phloem, which we have just described, deserves consideration. Opposite the protoxylem points of the diarch lower portion of the hypocotyl and of the root are formed two broad rays consisting solely of parenchyma cells of the type already described, and extending across the cambium to the periderm. These rays correspond in position with the primary medullary rays typical of woody roots, but to call them such in this case might prove misleading, because the cells of which they are composed differ fundamentally from those we generally associate with medullary rays. Alternating with these rays, two sectors of vessels and sieve-tubes are produced. As the organ thickens, these fork repeatedly, leaving gaps which are occupied by secondary rays of parenchyma. These rays of parenchyma are usually broad in comparison with the rays in which the vessels are distributed, and occasionally new wedges of vessels are formed in them, and these accordingly have no contact at their inner ends with the central mass of xylem (Fig. 2). The vessels in each wedge are separated by parenchyma cells similar to those of the parenchyma rays (Fig. 1). The groups of sieve-tubes lie imbedded

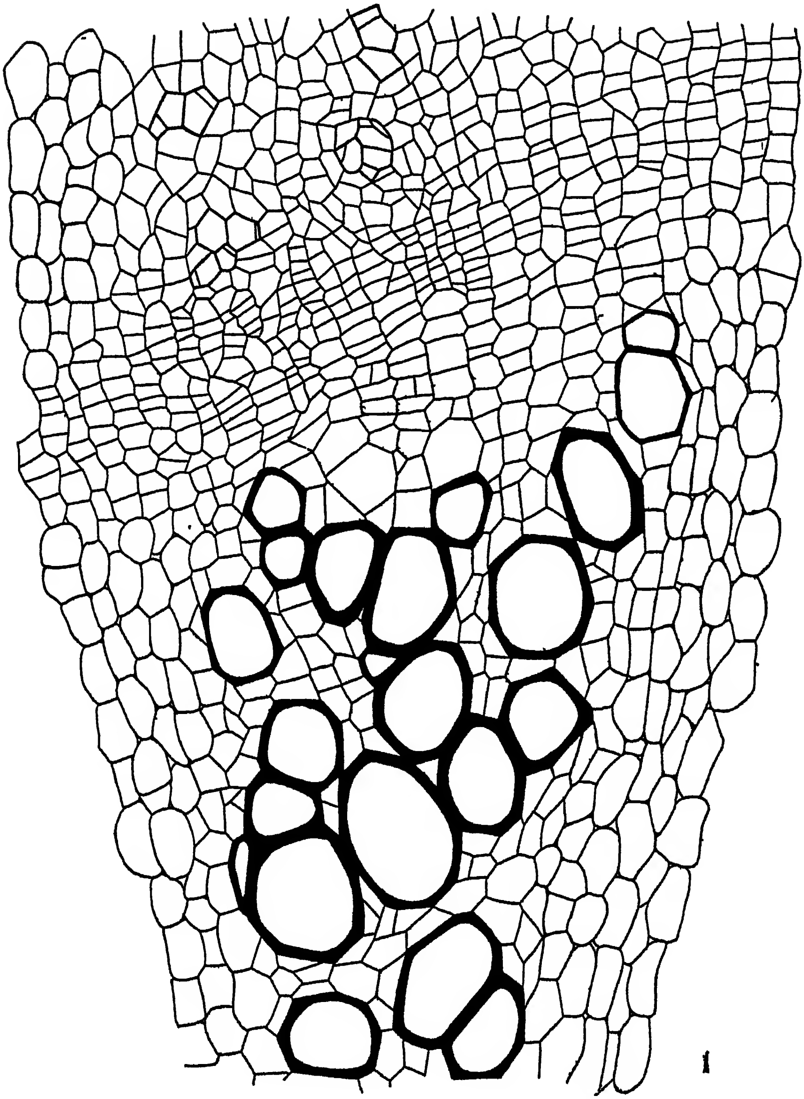
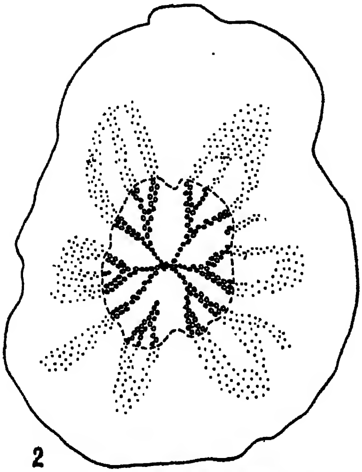


FIG. 1.—Cross-section of the tap-root of a plant about three months old, collected on August 10, showing a portion of a single wedge of vessels and sieve-tubes, with the intervening cambium and a portion of the parenchyma rays on either side. Notice the greater activity of the cambium in the wedge than on either side of it. (Camera lucida, approximately × 200.)

in parenchyma opposite the ends of the wedges of vessels and, when the latter fork, the masses of sieve-tubes also fork. This general sectorial



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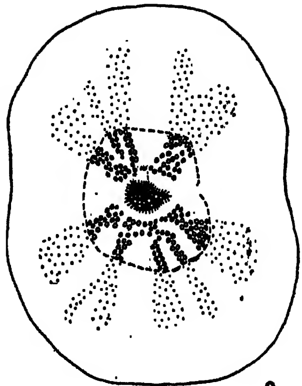

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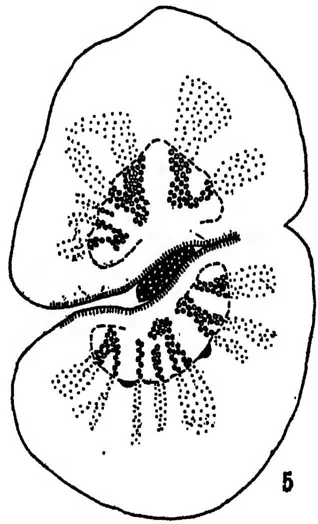

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FIG. 2.—Diagrammatic cross-section of the tap-root of a plant in its first summer, collected August 19, showing the embayment of the cambium in the primary xylem rays (at top and bottom of figure, × 6).

FIG. 3.—Another tap-root of the same age in which the central portion of the xylem has been cut out by periderm formation (in this figure as in Fig. 5, the primary rays lie across the page, × 6).

FIG. 4.—Cross-section of the tap-root of a 1-year-old plant, collected June 7, showing its dissection at this level into four strands (× 12).

FIG. 5.—A strong lateral root of a plant in its second summer, collected August 19, which has progressed farther in its late summer fission than the tap-root in Fig. 3 (× 6).

In all the figures cambium is indicated by broken line, periderm (where it occurs on interior surfaces only) by hatching, the approximate distribution of vessels by open circles, of sieve-tubes by coarse stippling. Living tissues shown in white, dead tissues in black. (All figures from camera lucida sketches.)

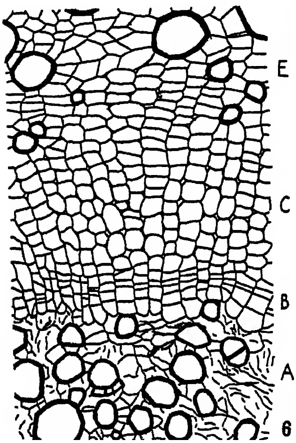
type of distribution of the conducting elements of the xylem and phloem is found elsewhere in the Boraginaceæ in *Anchusa, Alkanna, Heliotropium* and *Nonnea,* but in these genera fibres occur in the vascular sectors (Jodin).

The cambium is much less active in the rays of parenchyma than in the sectors of conducting elements. This retardation of division of the cambium where it crosses the parenchyma rays, while quite evident in the case of the narrower secondary rays (Fig. 1), is extremely pronounced in the case of the primary rays and the broader secondary rays. In the narrower secondary rays the difference in activity, as compared with the cambium which is giving rise to vessels and sieve-tubes, is manifested in late August by a smaller number of immature segments and by their generally greater size. In the very broad rays there is sometimes a complete cessation of activity by the cambium, which then disappears. Because of the more sluggish division of the cambium in the parenchyma rays, which results in the formation of fewer cells, the cells in both the xylem and phloem portions of these rays become distinctly elongated in the radial direction, in the broader parenchyma rays enormously so. Despite this elongation of the cells, deep embayments are often formed in the cambium ring where it crosses the broader rays (Figs. 2 and 3). Such a condition may be seen at the end of August in tap-roots from 6 to 8 mm. in diameter, with a cambium ring from 2.5 to 3 mm. across. The disappearance of the cambium from the parenchyma rays is described and figured by Jodin for the root of *Symphytum officinale.*

At this point it becomes necessary to discuss the storage of food in the plant. The reserve food of *Mertensia* is fat, rather than starch, as in the great majority of plants. Oil globules are very abundant in the late summer in all of the perennating portions, and in the spring they occur in great quantity at the growing point of the shoot, in the cortex, phloem, xylem and pith of the young stems, and in the region of the cambium of the new strands formed by the dissection of the older, buried organs. Small globules of oil occur even in the chloroplasts in the leaves. On the other hand, starch is regularly present only in the active sieve-tubes of stem and root, and in the cells of the starch sheath of the young shoot until the Casparian strips are differentiated in them. The distribution of fat in the tap-root presents several points of interest. In late August it was found that oil globules were abundant in and about the cambium, in the parenchyma of the vascular wedges and in that portion of the phloem containing functional sieve-tubes. At the same time, the globules were rare in the parenchyma rays, being almost absent from the centers

of the broader ones, and very sparse in the outer secondary cortex. The relative paucity of food reserves in the broader parenchyma rays is apparently correlated with the inactivity of the cambium where it crosses them.

In the more vigorous plants the tap-root may undergo fission during the first summer of the plant's life, and some of the most vigorous lateral roots become divided when they are still but a few months old. This late summer fission is by no means an invariable occurrence, and does not materially affect the form of the fission in the following spring, which is



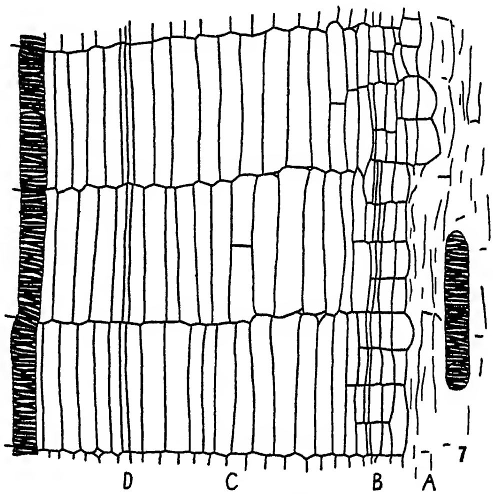


FIG. 6.—Enlargement of a region in the center of Fig. 3, showing, from bottom to top, the broken-down central xylem (A), the internal-periderm (B), the dilatation parenchyma (C), and the intact secondary xylem (E). (Camera lucida, × 100.)

FIG. 7.—Longitudinal section through the same root at a nearby level, at which the cambium (D) is still distinguishable (Free hand, × 115).

of universal occurrence. The first indication of instability at the center of the root is the dilatation of the parenchyma cells, often as a pronounced radial stretching by which the elements of the protoxylem are displaced or even occluded, and the primary structure of the xylem rendered unrecognizable. At the end of August, tap-roots were found in which the central portion of the stele, including protoxylem, metaxylem and a considerable portion of secondary xylem, had been cut out by a periderm, and its cells had degenerated (Fig. 3). The origin of this periderm could not be followed in any of the material available to me. Several layers of parenchyma cells, resembling those formed from the normal cambium

ring, had been produced between the periderm and the intact xylem, apparently by a cambium of limited activity (Figs. 6 and 7). At a higher level of the same tap-root, the cambium, which first had become deeply embayed across the center of the two primary parenchyma rays, had been produced inward along the edges of these rays until it joined the newly formed central cambium, and by this means each of the two portions into which the xylem had been split was surrounded by a complete ring of cambium. The central cavity, formed through the degeneration of the xylem, had broadened laterally along the primary parenchyma rays.

Fig. 5 shows a root in which the central cavity has become confluent on one side with a furrow progressing inward along the degenerating primary ray, and the organ is almost split in half. In the root shown in the figure, unlike the tap-root just described, an active cambium could not be traced completely across the inner faces of the two divisions of the xylem. In the following spring, by the commencement of what we shall term the "normal" fission, to distinguish it from this fission of sporadic occurrence now under discussion, tap-roots are found which have become divided locally into two strands. Because this "sporadic" fission is of irregular occurrence both in respect to time and to individuals, and but a small proportion of my yearling plants collected in late August exhibited it, it was not found possible to work out its origin as thoroughly as might be desired. It is important as an illustration of how strong the tendency to cut away nonfunctional tissues has become in the plant, rather than an aid to the understanding of the "normal" fission about to be described.

The behavior of *Mertensia* during the outset of the growing season was studied during a visit to Mt. Desert Island covering the first two weeks of June, 1928, when both field and microscopic observations were made, and liberal collections of material were gathered for subsequent examination in the laboratory. At the beginning of June, the vegetation on the Island, surrounded as it is by the cold waters of the Gulf of Maine, was still in the first flush of its vernal activity, with trees burgeoning and the spring flowers in bloom. On the seashore the young shoots of *Mertensia* were just sprouting up through the shingle, and they made great progress during the fortnight which followed.

At this time the cambium in the vascular wedges shows great activity, and the numerous thin-walled cells of which it is composed crumple in hand sections into a conspicuous, darkly-staining band. The many vessels formed at this time have very wide lumina, and so contrast sharply

with the narrow tracheæ formed in the preceding autumn (Fig. 24).* The cambium across the broader parenchyma rays is completely inactive and, because of this strict localization of growth in thickness, strains arise which result in the formation of large rents in the parenchymatous tissue of both xylem and phloem (Fig. 4) and the root has a shrunken appearance as seen from the exterior (Pl. III, fig. 5). This tissue is either already dead, or destined soon to become so. At about this time the youngest xylem and phloem is cut off from the older, inactive or dead tissue which surrounds it. The newly formed portion of a single wedge of vessels and sieve-tubes may be cut out to form a strand all by itself, or several such wedges, separated by narrow parenchyma rays, may be united in a single strand (Fig. 4). Mature parenchyma cells, lying between the narrow, scattered tracheæ which terminated each wedge of vessels at the cessation of growth in the preceding fall, become meristematic and divide very actively by tangential walls, forming a typical dilatation parenchyma. On the outer side of the future strand a stratum of mature phloem parenchyma cells, formed toward the close of the previous growing season, divides in a similar manner, but not quite so actively. Along the edges of the parenchyma rays which limit the active cambium, a row of the radially elongated cells divide by radially directed walls. These rows of cells dividing radially and tangentially are joined by others dividing in oblique planes, and so the newly formed portion of each wedge of vessels and sieve-tubes, or of a group of adjacent ones, is completely surrounded by a band of actively dividing cells.

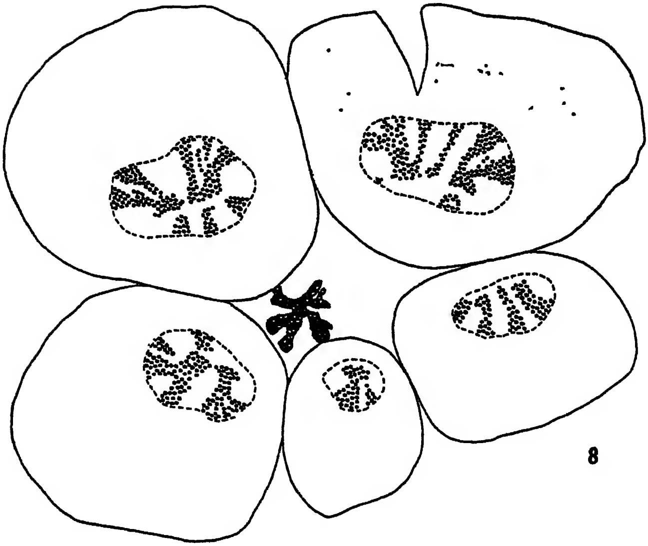
After the band of meristematic cells has arisen, certain changes become evident in a layer of parenchyma cells, usually one cell thick, but locally two, lying to the exterior of it. The walls of these cells thicken slightly and become suberized, and numerous oil globules, which stain bright red with alkannin, lie against them, both inside and outside their lumina (Fig. 26). A phellogen arises just within this suberized layer (Fig. 25). Its activity is limited, and about two or three layers of cork and one or two of phelloderm are formed, as in the case of the primary phellogen which arises beneath the endodermis. When the intraxylary meristem has produced about eight or ten layers of cells, the true cambium is produced around the edges of the group of vessels, and thence across the newly formed dilatation parenchyma (Fig. 25). Either the newly formed portion of a single wedge of vessels may be surrounded by a cambium ring

* The method of fission of the root so closely resembles that of the stem that the same set of figures has been used to illustrate both.

in this manner, or several together may be enclosed by the same cambium ring. A single strand of living tissue may contain one or more cambium rings, just as it may enclose the newly formed portions of a variable number of vascular wedges (Fig. 4).

In this manner all of the newly formed xylem and phloem is cut off by periderm from the older, dying tissue. Just as the dilatation parenchyma from which both phellogen and cambium is organized arises between the narrow autumn-formed vessels of the xylem, and preserves the outer ones in the strand of living tissue, so the periderm arises among the latest formed of the previous year's sieve-tubes, and a certain number of them with their surrounding parenchyma are thereby incorporated in the new strand. These old sieve-tubes may be clearly distinguished from those just formed by the thick pads of callose which cover their sieve-plates. Their lumina, as those of most of the sieve-tubes in the older, abandoned portion of the phloem, have been more or less completely occluded by the dilatation of the neighboring parenchyma cells, and accordingly are difficult to recognize in cross-sections. The tissues exterior to the new strands have by this time been entirely depleted of the oil globules previously stored in them. Only in the proximity of the extremely active cambium is an abundance of fat found in the tap-root at this season.

During the course of the summer the tissues thus cut off by the periderm decay away and the manner in which the root has been dissected is revealed externally. By the isolation and disintegration of the primary parenchyma rays, which, as we have seen, may have taken place during the late summer of the plant's first growing season, the tap-root has fallen into two major halves running the greater portion of its length. The plane of this primary separation was accordingly determined by the orientation of the protoxylem rays. The torsion of the tap-root obscures this division, and in some plants occasional strands, representing vascular strands which had cut obliquely across the primary parenchyma rays, bind together the two divisions of the tap-root. The lateral roots, which originate opposite the protoxylem rays, lie in the plane of this separation. Since the primary parenchyma rays of these are vertical, they have become divided, usually into two, in the same plane as the tap-root. One longitudinal half of each strong lateral root then joins each half of the tap-root, and forms a further connecting link between the two portions. Finally, each of the two primary divisions has become a network of anastomosing strands, each of which is free from the others for relatively short distances only. An idea of how rapidly the appearance of the cross-section of the tap-root may change may be gained by the comparison of



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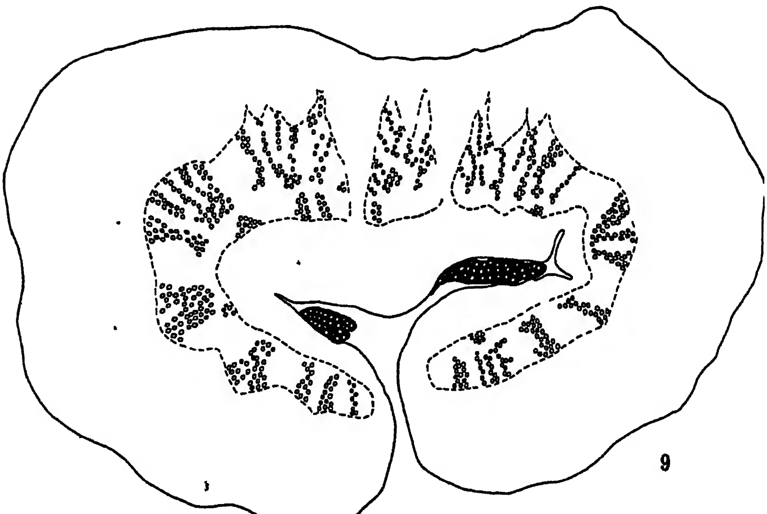

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FIG. 8.—Cross section of the tap-root shown in Pl. VII, fig. 13, collected August 19 of the second summer of the plant's life (× 6).

FIG. 9.—The same root about 1 cm. lower down (× 6). The symbols are the same as in Figs. 2-5. (Both figures from camera lucida sketches.)

Fig. 8 with Fig. 9, which represent cross-sections of the root shown in Pl. VII, fig. 13, at levels one centimeter apart. At the level of Fig. 9 the root was flattened out between two stones, the pressure of which was perhaps responsible for its failure to divide in the normal way.

The first cells formed by the arc of intraxylary cambium are parenchyma cells of the type already familiar in the unsplit root. In the more vigorous strands new vascular bundles are soon initiated by this cambium, which forms vessels on its concave face and sieve tubes on its convex face. The orientation of these bundles is then normal in respect to each particular strand, but inverted when considered in relation to the primary cambium ring of the unsplit organ. Thus the new strand becomes a radial but decidedly eccentric structure. In the case of the weaker strands, new bundles are not always initiated by the arc of intraxylary cambium, which during its limited period of activity continues to cut off parenchyma cells alone. In either case a much greater thickness of cells is formed toward the outside of the root than toward the inside (Fig. 8).

The subsequent fissions of each strand, the origin of which we have just traced, involve no new principle. Toward the end of the growing season at the outset of which they were formed, the central portion of the very strongest strands, which attain the diameter of an undivided tap-

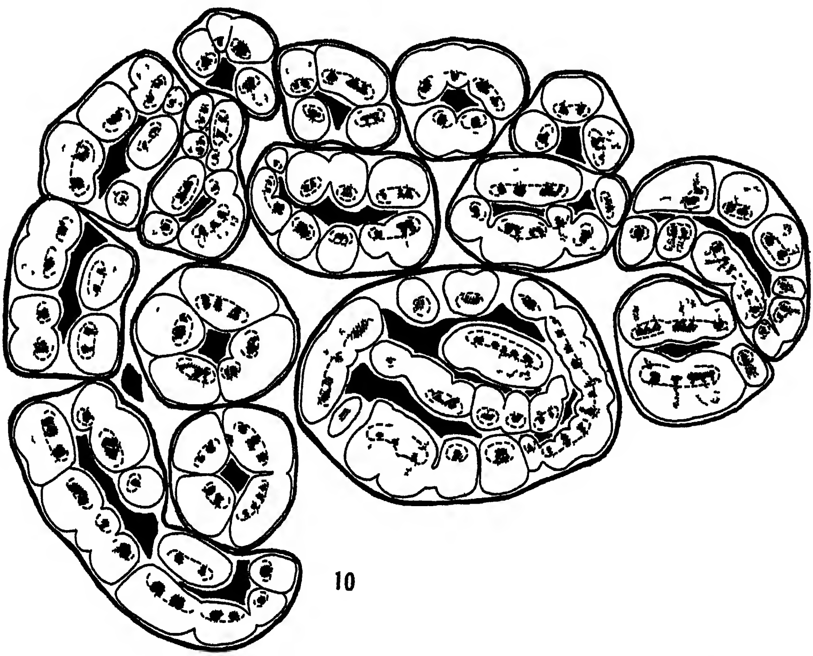

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FIG 10.—Cross-section of the tap root shown in Pl VIII, fig 15 collected August 19 of the fourth summer of the plant's life (it is somewhat more than three years old) Vessels occur in the obliquely hatched areas, sieve tubes in stippled areas, cambium is indicated by broken lines, dead tissues by solid black (Free hand, × 25)

root, may be cut out by a periderm, just as happens in the case of the tap-root, and has been described as "sporadic fission." The actual fission of the strands by this method has not been observed. In the spring following that in which the primary fission occurs, the newly formed portion of each vascular ray which the strand contains is isolated from the older tissue by periderm (Fig. 27). The cambium is produced through the intraxylary dilatation parenchyma, and the cycle of thickening, fission and thickening begins over again. Fig. 10 shows a tap-root of a plant in its fourth summer, which has accordingly gone through three periods of fission, and consists, at the level of the figure, of seventy-four separate strands, a number which would have been greatly increased in the following spring (Pl. VIII, fig. 15). As a plant becomes older, and consists of a greater number of strands, the intraxylary cambium in each does not as a rule initiate new vascular bundles before the next dissection in the following spring. The strand accordingly does not acquire a radial structure, and the new strands into which it becomes dissected lie all to one side, and are orientated in the same way. Nevertheless, the multiplication of strands still continues as a result of the radial forking of the vascular wedges contained in each older strand.

The course of events in the more slender lateral roots, although in principle the same as that just described for the tap-root and stronger laterals, differs considerably in detail. It will be remembered that these roots, as well as the primary root, are diarch. Two broad parenchyma rays are formed opposite the protoxylem points, and alternating with these are two sectors in which vessels and sieve-tubes are produced. Each sector may fork once or rarely more, or may remain undivided, and there are usually only two or three wedges of vessels in the thin roots. The thickening of the root may be symmetrical or more or less eccentric, in some cases extremely so, with the wedges of vessels and sieve-tubes directed entirely to one side. In the following spring the periderm which cuts off the older tissues may follow one of several courses. In the simplest case, which is found in the most slender roots, a single ring of periderm roughly concentric with the cambium is formed through the secondary phloem. When this occurs, all of the xylem, including the primary xylem, is preserved in the single strand of living tissue which lies in the center of the root, while the older phloem is cut off and decays. During the succeeding summer, one can distinguish such roots from the young roots, which have undergone no periderm formation inside the pericycle, only by the alternation of small and large vessels in the former, marking the transition from autumn to spring growth. In

other roots, and this is a method which is most likely to be followed in the more eccentric ones, the periderm encloses an open ring of tissue, for a deep embayment on the least thickened side of the root cuts out the central xylem. Usually the primary xylem is cut out by this invagination of the periderm (Fig. 11), but this is not always the case, for sometimes the embayment misses the primary xylem, while including a portion of the older secondary xylem to one side of it. Finally, in the case of extremely eccentric roots, the new strand lies entirely to one side of the center, and resembles that formed from a single sector in the hypocotyl. The same root which at its base is dissected according to one scheme, may follow another scheme nearer the apex, where it is more slender. One of the chief differences, then, between the weaker roots and the other perennating portions of the plant, tap-root and subterranean stems, is that in the former the central xylem sometimes sur-

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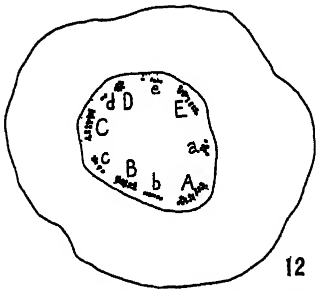
FIG. 11.—Cross-section of a slender root collected in the spring of its second year, showing the method of dissection. The symbols are the same as in Figs. 2-5. (Camera lucida, × 17.)

vives the general pruning away of older tissues, which occurs every spring, and is included in the newly formed strand, while in the latter the primary xylem and the older portions of the secondary xylem are always cut away.

ANATOMY AND FISSION OF THE STEM

Considerable study has been devoted to the anatomy of the etiolated shoot, and the important differences between this and the normal, green shoot are in general well known. It has been usual, however, in the investigation of the anatomical peculiarities which accompany etiolation, to grow the plants intended for study in darkness artificially produced, and the knowledge gained from these studies has been considered valuable chiefly in the interpretation of the physiological processes of the plant, much as the study of certain pathological conditions has thrown light on the normal physiology of the animal body. The knowledge of

the changes caused by etiolation are not usually essential, however, to the understanding of the structure of the plants of the same species growing in their natural habitat. In *Mertensia*, on the contrary, the peren-



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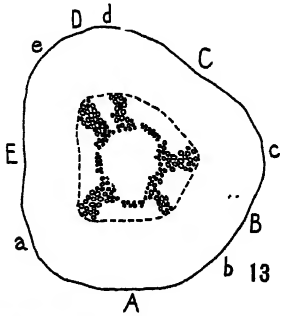

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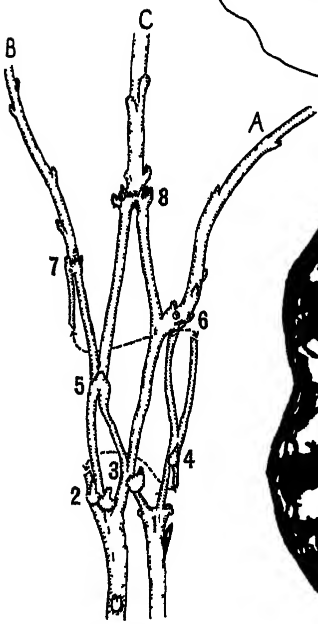

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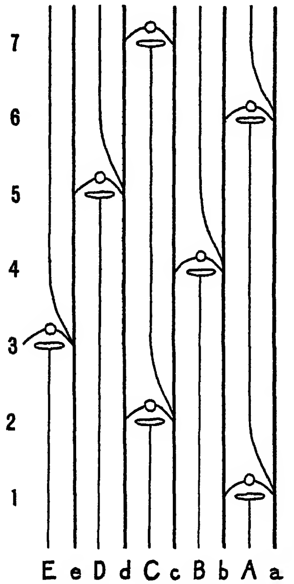
FIG. 12.—Cross-section of a young aerial shoot showing the arrangement of the common (A-E) and cauline (a-e) bundles, lettered to correspond with a section just below node 1 in Fig. 16. (Camera lucida, × 8.)

FIG. 13.—Cross-section of the buried base of a stem about three months old, collected August 19. (Camera lucida, × 9.)

FIG. 14.—The dissected base of a stem late in its second summer, showing the arrangement of the strands. The nodes are numbered 1-8. Three lateral branches of the dissected main axis are lettered A, B and C. For clearness, the strands have been cut in two places and spread apart. The severed ends are connected by broken lines (× ¾).

FIG. 15.—Cross-section of a very vigorous 1-year-old buried stem, collected in early June, showing its dissection at this level into eight strands. The symbols are those used in Figs. 3-5. (Camera lucida, × 8.)

nating etiolated bases of the shoots play an imporant rôle in the economy of those plants which have been buried by the shingle, and their anatomy, differing fundamentally from that of the shoots growing in the light, must receive careful consideration. We shall treat first the structure of the decumbent aerial shoots, and later that of the bases of the shoots which grow up through the shingle.



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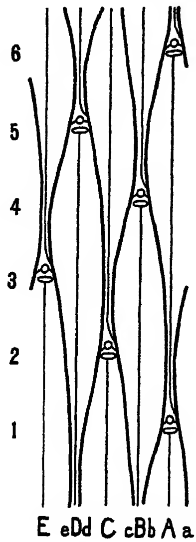

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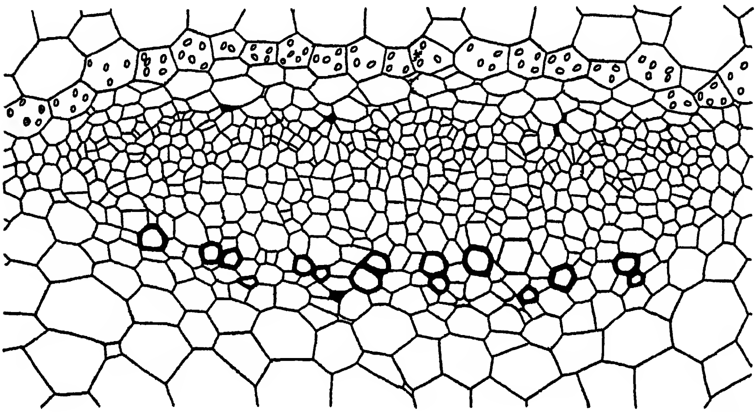
FIG. 16.—Diagram to show the course of the vascular bundles in an aerial or very vigorous buried stem. The common bundles (A-E) are indicated by thin lines, the cauline bundles (a-e) by heavy lines.

FIG. 17.—Diagram to show the course of the bundles in a more slender buried stem.

The phyllotaxy of *Mertensia* is $\frac{2}{5}$, and the spiral on which the leaves lie may be either right-handed or left-handed. A cross-section through a young, unthickened, aerial shoot reveals usually ten broad, shallow vascular bundles (Figs. 18 and 19) five of which contain considerably more protoxylem elements than the other five which alternate with them (Fig. 12). The five stronger bundles are common bundles or leaf-traces, the alternating weaker bundles are cauline. The cauline bundles (Fig. 16 **a-e**) run straight up the stem. Whenever a cauline bundle passes the proximal side (as one follows the spiral of phyllotaxy up the stem) of a leaf insertion, it gives off a branch on its own distal side. This branch becomes the common bundle which replaces the one that

has just bent out into the petiole, runs straight up the stem through five internodes and enters the next leaf above in the same orthostichy. Thus all of the leaves of the same orthostichy are entirely dependent upon the same cauline bundle. In the base of the petiole the common bundle gives off branches to the right and left, which in turn imme-



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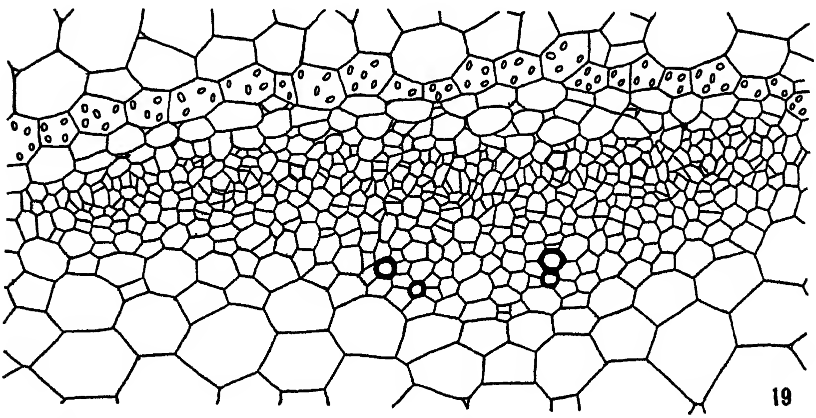

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FIG. 18.—A common bundle in an internode 6 mm. behind the apex of a shoot collected in early June. The cambium is just beginning to differentiate. The starch-sheath may be followed by its included starch grains. Notice the lacunæ left by the disruption of the earliest protoxylem and protophloem elements, some of which are already clogged by a darkly staining substance (× 235). This is not the bundle which leaves the stem at the next node above.

FIG. 19.—A cauline bundle at the same level (× 235).

(Both figures from camera lucida sketches)

diately branch several times to form the subordinate bundles of the petiole. So the broad, channeled petiole comes to have a strong central bundle and from three to seven weaker bundles of various degrees of development on either side of it. The branch traces, two in number, arise from the two cauline bundles which pass on either side of the leaf-trace (Fig. 16).

The differences between the common and the cauline bundles are quite fundamental, and with a little practice each can be recognized at a glance at practically any level of the shoot. Two millimeters behind the apex of a rapidly growing shoot the first protoxylem elements of both types of bundles have become lignified, so there is no great difference in the time of maturation of the earliest protoxylem in the two types. On the other hand, the common bundles are far better supplied with vessels than the cauline bundles (Figs. 18 and 19). A few millimeters behind the apex a count of the number of lignified conducting elements in each bundle gave the following results:

Common bundles-22, 12, 14, 23, 11—Total 82.

Cauline bundles- 4, 4, 10, 4, 5—Total 27.

Ratio—Elements in common bundles: Elements in cauline bundles :: 3:1.

Despite this difference in the number of differentiated elements, both types of bundles occupy about the same proportion of the circumference of the stele. Although there is much variation in the tangential extent of different bundles of even the same type, on the average the procambial cells of one type occupy arcs about equal to those of the other type. In the third elongated internode behind the condensed apex, the count stood as follows:

Common bundles-32, 22, 14, 32, 19—Total 119.

Cauline bundles-15, 12, 6, 9, 8—Total 50.

Ratio—2.4:1.

Here the fascicular cambium was becoming differentiated. In the eighth internode of the same stem the numbers were:

Common bundles-44, 25, 37, 24, 30—Total 160.

Cauline bundles-15, 21, 12, 19, 27—Total 94.

Ratio—1.7:1.

At this level the interfascicular cambium was becoming differentiated. Already the most recently formed tracheæ in the cauline bundles were of considerably greater diameter than those in the common bundles. In the twelfth internode:

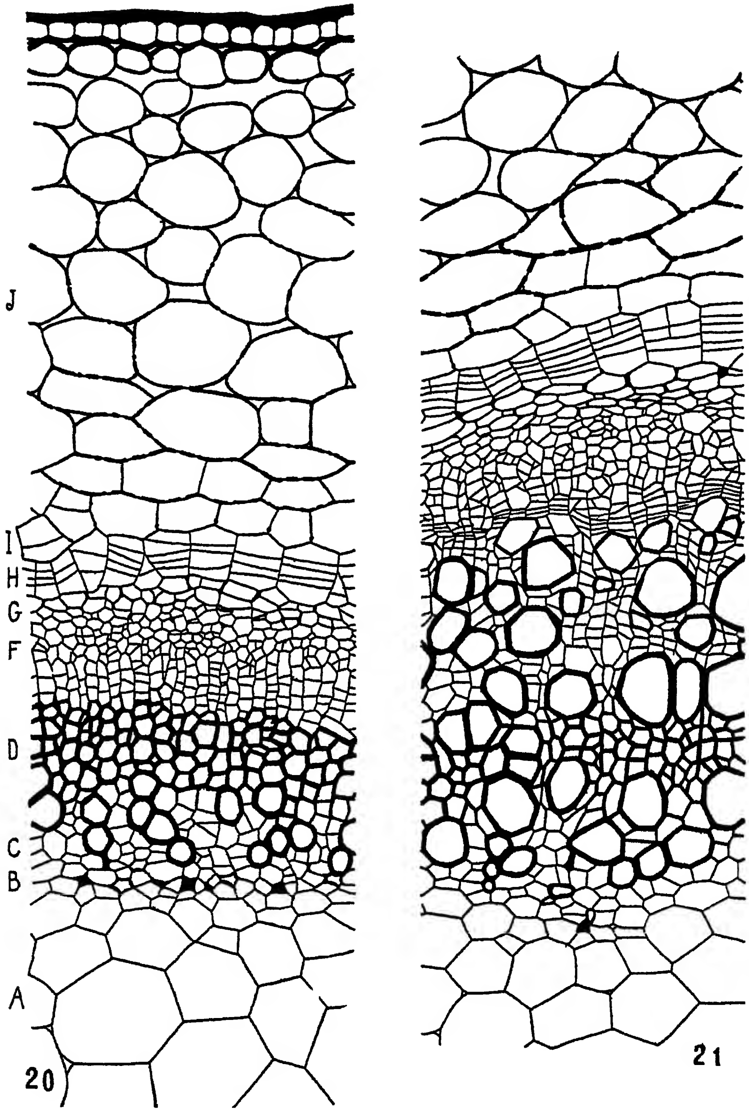

FIG. 20.—A strip through a secondarily thickened common bundle about 18 cm from the base of an aerial stem collected on August 19 of its first summer (× 150).

FIG. 21.—A strip through a nearby cauline bundle (× 150).

From bottom to top of both figures: A = pith, B = protoxylem, C = metaxylem, D = secondary xylem, E = cambium, F = secondary phloem, G = primary phloem, H = periderm, I = endodermis, J = cortex. (Both figures from camera lucida sketches.)

Common bundles-62, 44, 53, 28, 52—Total 239.
Cauline bundles-36, 41, 22, 28, 46—Total 173.
Ratio—1.4:1.

At this level considerable secondary xylem had been formed in both sets of bundles. The mere statement of the number of conducting elements does not give a fair idea of the relative importance of the two types of bundles in water transport, for the average diameter of the vessels in the cauline bundles was considerably greater than in the common, and so the relative efficiency of the former was very much greater than appears from the bald numerical statement. From this time on an active cambium continues to augment the number of vessels in the cauline bundles, while few or none are added to the common bundles, so that by August the difference in the appearance of the two types is very striking (Figs. 20 and 21). The lumina of the largest vessels present in the cauline bundles at this time average 58μ in diameter, while those of the common bundles average only 32μ. The average cross-sectional area of the former is more than three times as great as that of the latter, and their efficiency in conduction correspondingly greater.

This inversion of the relative development of the two types of bundles as growth proceeds is exactly what one would expect on the assumption that the degree of development of the conducting elements is conditioned by the demands made upon them by transpiration. In the fifth internode behind the youngest actively transpiring leaf no cauline bundle is needed for conduction, except to supply the relatively slight water requirements of the growing point, while each of the five common bundles must take care of the transpiration stream directed to a transpiring leaf (Fig. 16). In the eleventh internode each of the cauline bundles must take care of one transpiring leaf, and one of them of two; in the sixteenth, all with two and one with three, etc., while no common bundle ever supplies more than one leaf. Since the aerial stems of *Mertensia* as a rule remain unbranched, the water supply of the dormant or only slightly active lateral buds has been left out of consideration in the present discussion.

After the initiation of the cambium a complete ring of lignified secondary xylem is laid down, a condition found in a number of other herbaceous Boraginaceæ. This ring consists of tracheæ of the sort already familiar to us in the root, lignified parenchyma cells, transitional forms between these and fibres, and relatively few genuine fibres of the libriform (simple-pitted) type. In Fig. 22, **e** is a parenchyma cell, similar in shape to those which make up the bulk of the secondary xylem

of the root and subterranean stem, and of the same length as the cambium cell from which it was cut off, but with its walls thickened, lignified and penetrated by simple pits. These cells lie in horizontal, radial series, as has already been described for the root. In the same figure, **b**, **c**, **d**, **f**, **g**, **h** and **i** are cells of this general shape which have sent out one or more processes, in shape often reminiscent of the pseudopodia of a rhizopod, which have advanced by sliding growth between the ends of the cells of the next series above or below, while the bodies of the cells maintain regular horizontal ranks. In cross-sections (Figs. 20 and 21) the smaller lumina lying between the corners of the large cells making up the schlerenchyma ring are those of the processes from the cells of the next series above or below the level of the section. True fibres, such as that represented in Fig. 22, **a**, are much rarer than these transitional forms.

In the common bundles, the cambium gives rise to four or five layers of schlerenchyma cells in which few or no vessels are included, then to a few layers of unlignified parenchyma cells and by the middle of August has become inactive (Fig. 20). There is some variation in the degree of development of different bundles, or rather of different levels of the same bundle. Near the insertion of the leaf which it supplies, the formation of vessels in the secondary xylem of the common bundle is rare, while at the other end of the bundle, near its point of origin from the cauline bundle, a few vessels may be scattered in the schlerenchyma, and an occasional one may be formed after the schlerenchyma ring has been completed. Where a common bundle lies close between two cauline bundles—a condition which often occurs near its point of origin from one of them—it may be thickened much as is the latter. In the cauline bundles many large vessels interrupt the schlerenchyma ring, and after forming five or six layers of schlerenchyma cells, the cambium continues to form numbers of large vessels separated by thin-walled parenchyma cells. In late August, at a time when the cambium of the common bundles has become entirely quiescent, that in the cauline bundles is in a state of active division (Fig. 21). The interfascicular cambium never gives rise to any conducting elements, so the vascular bundles remain entirely distinct. After forming a few layers of cells which complete the schlerenchyma ring, this portion of the cambium gives rise to thin-walled parenchyma alone. Near the apex of the shoot the lignified cells are thin-walled or locally absent, and a continuous ring of schlerenchyma is not formed. Here, too, since the degree of secondary thicken-

ing is much less, the contrast between the two types of bundles does not become so pronounced as nearer the base of the shoot.

The pericycle and phloem consist of thin-walled cells, and pericyclic or bast fibres, which are usually absent in the Boraginaceæ (*Heliotropium,* with pericyclic fibres, constitutes an exception) are not formed in *Mertensia.* The sieve-tubes of the protophloem are early disrupted, and their cavities, more or less occluded by the neighboring parenchyma cells, become filled with a dark-staining substance (Figs. 20 and 21). As with the xylem, so there is a markedly greater development of the secondary phloem in the cauline than in the common bundles, where at most one or two layers which include sieve-tubes are formed.

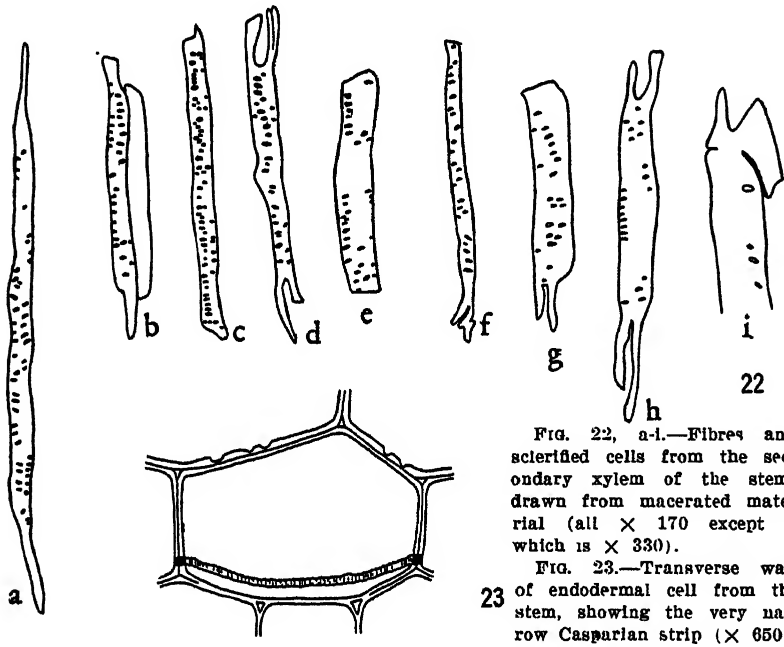

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FIG. 22, a-i.—Fibres and sclerified cells from the secondary xylem of the stem, drawn from macerated material (all × 170 except i, which is × 330).

FIG. 23.—Transverse wall of endodermal cell from the stem, showing the very narrow Casparian strip (× 650).

In the lower half of the stem a distinct endodermis is present, its cells characterized by a very narrow Casparian strip, which is situated near the inner tangential wall (Fig. 23). In the upper portion of the shoot a starch-sheath takes its place. I have found no mention of an endodermis in the stem of the Boraginaceæ, and Jodin does not describe or figure it. In *Mertensia virginica,* which I examined, an endodermis of the type present in *M. maritima* surrounds the stele in all but the most apical portions of the stem, and an arc of it subtends the abaxial side

of each of the vascular bundles through the petiole. At the base of the shoot of *M. maritima* periderm may arise tardily in the pericycle, and in one stem as many as eight layers of cells had been formed by August, but even here the primary cortex persists throughout the life of the aerial shoot. The cells of the inner region of the cortex (Fig. 20) are large, with walls prominently but rather unevenly thickened, and penetrated by conspicuous pits. They merge gradually into an outer region of smaller cells which in places are rather irregularly collenchymatous, and are separated by large intercellular spaces. The pith is composed of large cells, which in thick, vigorous shoots break down and leave a medullary cavity. It is not, however, cut out by a periderm, as in the case of the etiolated shoot.

We have next to consider the etiolated shoots, which in the spring push out from the dormant buds of plants recently buried by the shingle, and make their way up through the overlying stones. In forcing their irregular passage, these slender, brittle, white shoots, bearing leaves reduced to scales, become extremely contorted, so that it was found impossible satisfactorily to determine their phyllotaxy by external count. To add to the confusion, a cross-section of the more slender of them reveals six, five or, more rarely, only four vascular bundles in the narrow stele. Fortunately the more vigorous of these shoots show the normal ten bundles, and by following down a series arranged in the order of increasing reduction it is possible to account for the vascular structure of even the most slender of them. The course of the bundles was plotted from camera lucida drawings made from serial hand-sections, and it was found that the diagrams could be systematized only on the assumption that the phyllotaxy remained the normal $2/5$, even although the number of bundles found in a cross-section was reduced to six or five.

The type of stele most frequently encountered in buried shoots shows six or sometimes seven bundles in cross-sections made at various levels of the same stem. Pl. IX, fig. 18, shows such a stem after it has been secondarily thickened. Such a condition arises in the following manner: To begin with we must recognize ten bundles, five common and five cauline (Fig. 17), although in any cross-section several of these are so closely associated that the medullary ray does not develop between adjacent bundles, and they are accordingly indistinguishable. Thus, when the leaf-trace **A** bends into the petiole at node 1, the cauline bundles **a** and **b** become confluent above the leaf gap. The common bundle **A** ^{1},*

* In like manner bundle **B** ^{1} replaces **B**, **C** ^{1} replaces **C**, etc., after the latter have bent out to supply their respective leaves. All bundles bearing the same capital letter lie in the same vertical rank, and are not designated separately in Figs. 16 and 17.

which replaces **A** and which in a vigorous green shoot would separate from **a** near this level, remains sandwiched between the two. In the internode between nodes 1 and 2 we have a single bundle $\mathbf{bA^1a}$ with a triple valence. First, about one internode higher up, the cauline bundle **a** branches off to the right to join **e** above the insertion of the leaf at node 3, then, somewhat higher up, **b** separates to join **c** above node 4, leaving $\mathbf{A^1}$ to continue alone to its leaf at node 6. In any internode, we usually find three distinct common bundles, which will enter the first three leaves above, one distinct cauline bundle, and two common bundles each surrounded by two cauline bundles. The composite bundle generally occupies a greater arc than any single bundle, and after it has become secondarily thickened, it can generally be distinguished by the fact that the vessels lie in two arms. In Pl. IX, fig. 18, the large cauline bundle at the top of the figure is single, the broad bundles at the right and left are, as explained, triple. These alternate with three inconspicuous common bundles.. A much slighter degree of fusion between bundles (i. e. between **bBc** and **dDe**) is evident in Fig. 13. The smaller metaxylem elements of the common portion of a triple bundle can frequently be picked out in the midst of the larger vessels belonging properly to its cauline components.

In still more slender etiolated shoots, a reduction to only four distinct bundles has been observed. The whole group **cBb** (Fig. 17) may fuse with **a** above node 1, instead of **b** alone separating from **cB** and forming the fusion. Thus we obtain the following grouping of bundles:

(E) (eDd) (C) ($\mathbf{cBbA^1a}$)

Somewhat higher in the internode the bundles separated as follows:

(E) (eDd) (C) (cB) ($\mathbf{bA^1a}$)

In the formation of an independent common bundle, say **D, Dd** first separates from **e**, and then **D** separates from **d**. Such a drastic reduction in the number of bundles as that illustrated above is rare but, as a rule, the weaker the shoot, the longer such groupings as (**bBa**) and (**cBb**) remain confluent.

As in the green aerial shoot, the common bundles in the etiolated shoot, at first better developed than the cauline bundles, lag behind them in secondary thickening. Indeed, the difference in the production of conducting elements is here still more pronounced, because these common bundles never supply any transpiring leaves, while the cauline bundles must take care of all of the leaves which the shoot develops after it emerges from the shingle. The schlerenchyma ring is completely suppressed in the buried stem, and the elements of the secondary xylem and phloem are identical with those of the root. The cauline bundles are

thickened by the addition of vessels separated by parenchyma cells on the one side, and by sieve-tubes separated by parenchyma on the other. In the common bundles a few conducting elements are sometimes added during the early part of the season, but thereafter parenchyma cells alone are formed, and the group of sieve-tubes in the primary phloem becomes separated from the group of vessels in the primary xylem by a broad expanse of uninterrupted parenchyma. By late August the cambium of the common bundles, which has never produced as many layers of cells as that of the cauline bundles, becomes inactive and occasionally disappears entirely from the center of the bundle. In this respect the common bundles resemble the parenchyma rays of the root. Although no conspicuous embayment of the cambium is observable here, the thickness of secondary xylem and phloem on the radii of the common bundles is considerably less than that on the radii of the cauline bundles, with the result that the stem as a whole, as well as the cambium ring, becomes angular, with the cauline bundles lying at the angles (Fig. 13). As in the root, the distribution of oil globules follows that of the active conducting elements. While globules are not rare in the secondary xylem parenchyma of the common bundles, they are scarce in the secondary phloem, where they would lie in cells still farther removed from the active conducting elements of the cauline bundles. An exception to the general behavior described for the common bundles in this paragraph is found where these are so closely associated with cauline bundles on either side of them that the thickening of the three fused bundles proceeds almost as a unit.

The starch sheath present at the apex of the etiolated shoot becomes altered a few millimeters farther back into a typical endodermis with Casparian strips usually broader and more prominent than those described for the aerial stem, upon which the starch disappears from these cells. Casparian strips could never be traced beyond a point that was still 15-20 cm. from the apex of a rapidly growing green shoot. Priestley (*17*) found that in the etiolated shoots of *Vicia* and *Pisum* the starch sheath rapidly became converted into a true endodermis, although in the normal stem of these species it is present only at the very base, and that with the formation of the Casparian strip the starch disappeared from the cells. In the etiolated shoots of *Mertensia* a phellogen arises beneath the endodermis in the outermost layer of the pericycle, just as it does in the root, and the primary cortex dies away, so that by the middle of August no trace of it remains. As in the hypocotyl, the initia-

tion of this phellogen is preceded by the suberization of the entire wall of the endodermal cells. The cauline periderm resembles that of the root in its degree of development.

The pith also is always cut off from the living tissue by a periderm, just as in the root the central portion of the xylem is sometimes cut out (Pl. IX, fig. 18). The pith in the slender etiolated stems is usually solid, not hollow as in the thicker aerial stems. At about the same time that the phellogen arises in the pericycle, the walls of the outermost layer of the large cells of the central pith become suberized. The smaller cells of the layer external to this then divide by tangential walls, and a phellogen which completely surrounds the pith is organized. The medullary periderm usually consists of a few more layers of cells than the external periderm.

From what has been said it can be seen that the buried shoot, in its secondary development, very closely resembles the hypocotyl and root in the following particulars:

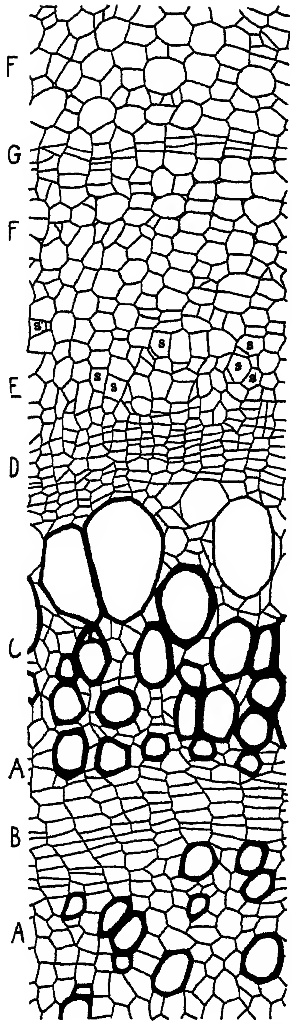
1. There is an endodermis beneath which arises a periderm cutting off the primary cortex. The development of this periderm is very similar in both organs.

2. Schlerenchyma is not formed either in the root or in the buried stem, and the secondary xylem and phloem are the same in both.

3. Just as the cambium is less active in the parenchyma rays than in the vascular segments, so it is less active in the common bundles than in the cauline. It often dies out in August both in the broad parenchyma rays of the root and in the common bundles of the stem.

4. The central portion of the stem (the pith) is always cut off by periderm, and similarly the central portion of the root (the primary and some secondary xylem) is sometimes cut off by periderm from the more active tissues.

Considering these resemblances, it is not surprising that in the following spring the dissection of the stem should follow the same method as that of the root. In the material collected in early June the cambium of the cauline bundles had become very active, and had formed numbers of large vessels which contrasted sharply with the small vessels formed in the previous autumn (Fig. 15). The local thickening had resulted in the deep embayment of the cambium ring over the common bundles. This portion of the cambium was totally inactive, perhaps already dead. The strains set up by the unequal growth in thickness resulted in numerous rents in the parenchyma of all regions, the most conspicuous of



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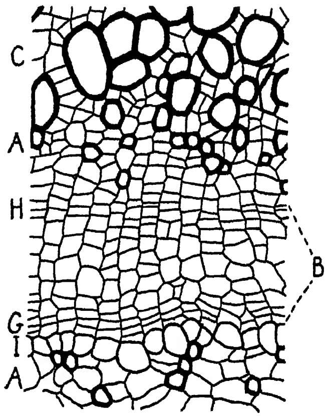

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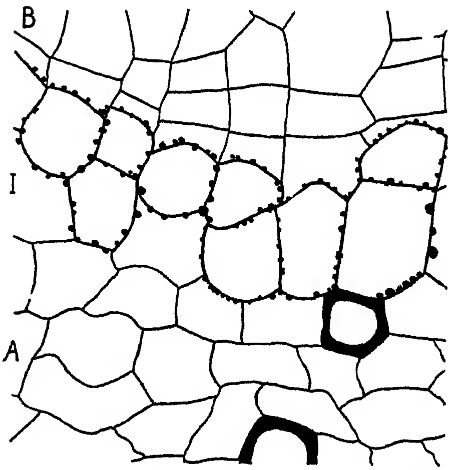

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FIG. 24.—A radial strip through one of the strands of the stem depicted in Fig. 15, showing, from bottom to top, the narrow vessels formed at the end of the previous growing season (A), the dilatation parenchyma which arises between these (B), the large spring vessels (C), the very active cambium (D), the newly formed phloem (E) and the old phloem (F) interrupted by the outer phellogen (G). (× 140.)

FIG. 25.—Detail from the tap-root in Fig. 4, showing the formation of cambium (H) and phellogen (G) in the dilatation parenchyma (B). (× 140.)

FIG. 26.—Detail from the cross-section of a tap-root treated with alkannin, showing the layer of suberized cells (I) which surrounds each strand before the periderm is differentiated, and the numerous oil globules which lie against the walls of these cells (× 535).

(All figures from camera lucida sketches.)

which were large, triangular lacunæ which developed on the radius of each common bundle. The histology of the formation of a phellogen around the new tissue of each cauline bundle, and the completion of the cambium ring surrounding the xylem of each new strand by its production through the intraxylary dilatation parenchyma are so similar to what occurs in the root that to describe it would be needless repetition. It is only necessary to add that a new medullary periderm arises beneath the old one and cuts off the latter, which now lies free in the central cavity of the shoot, and may be pulled out in the form of a long, corky tube. This last burst of meristematic activity on the part of the outermost perimedullary cells seems utterly useless, for in a short time they, together with all of the tissues which surround them, will cease to be a portion of the living plant.

The course and development of the strands into which the stem disintegrates is determined by the arrangement and activity of the lateral buds. In the previous autumn the terminal aerial portion of each shoot had died and during the winter it had decayed, so that now unless a bundle serves as a vascular connection for a lateral bud or branch, its presence is of no use to the plant. Such useless portions of bundles do not give rise to new strands in the spring, but are cut off by periderm from the living tissues and soon decay away. Every strand which is formed on the dissection of the stem is in actual service as a conducting channel to an active lateral bud which is developing into a shoot. The plant follows the principle of strict economy and every useless portion is rigidly pruned away.

If every cauline bundle gave rise to a single strand, these would follow the scheme of arrangement of the heavy lines in Fig. 16. Wherever a cauline bundle passes a lateral bud or branch, it gives off a branch-trace to it, and by these the strands are joined in pairs at successive nodes. Thus the strand derived from cauline bundle **c** would be joined alternately with **b** and **d** at regular intervals, **d** with **c** and **e**, etc. In passing to the left, from **c** to **e**, the strand **d** runs free through three internodes, in passing to the right, from **e** to **c**, the same strand runs free through two internodes. Such a regular arrangement of strands is sometimes found, and Fig. 14 illustrates an actual case of this.* Here we have, formed entirely by the activity of the plant, a solid model illustrating the course of the cauline bundles. Unfortunately, one may

* It should be noticed that while Figs. 16 and 17 are based on a left-handed spiral of phyllotaxy, Fig. 14 is drawn from a shoot with a right-handed spiral. The text refers to the former figures.

often examine dozens of dissected stems in a vain search for such perfect examples, for they are quite in the minority. The reasons for the failure of most stems to show the expected pattern are several:—

1. Unless a lateral bud actually becomes active in the spring, the bundles upon which it is immediately dependent do not form new strands, but decay during the ensuing summer. It will be noticed that above node 7 in Fig. 14 there are only two strands, those which supply the branch C arising from the next node. A large plant, which had not been deeply buried in the second winter previous to our examination of it, may have sent up a great many stems, the short buried portion of none of which bore three buds active in the spring during which its dissection occurred. It will be seen that unless there are at least three branches, not enough strands to fill the pattern will be preserved. One finds many flowering shoots apparently bifurcated at the base. These two strands represent all that is left of the parent stem of which this is the only branch.

2. Because of the fusion of bundles so frequent in the more slender stems, the newly formed portions of two fused cauline bundles are incorporated in the same strand, with the result that only a single strand is found immediately above a bud. This strand soon forks, however, as its two components must supply different buds higher up, and even where it is externally single, a cross-section usually reveals its double valence. It may contain two cambium rings, or a single one with a bifurcated bundle.

3. A single cauline bundle may be divided into more than one strand. When a vigorous, young plant has been deeply buried, it usually sends up one or two shoots into which all of its energy of growth is thrown (Pl. VII, fig. 14). These shoots, unlike most of the etiolated shoots, not only show the full number of distinct bundles in cross-section, but some of the cauline bundles may fork, and in the following spring each fork gives rise to a strand, just as occurs with each wedge of vessels and sieve-tubes in the root. The stem shown in Fig. 15 has given rise, in this manner, to eight distinct strands at the level of the cross-section. In another stem as many as fourteen strands were counted at one level. Strands representing the same cauline bundle can be recognized by the circumstance that they usually anastomose among themselves between their connections at the buds with other cauline bundles, but there is never any anastomosis between strands from distinct cauline bundles.

The subsequent history of the strands into which the stem falls as the dead tissues in which they are imbedded decay away, presents no new points of interest. One would be at a loss to distinguish, from its appearance in cross-section alone, a strand arising from the dissection of the stem from one arising from the dissection of the root. Each stem strand becomes dissected anew every spring precisely as in the root. All of the strands representing the dissection of a single cauline bundle usually remain connected at the nodes where the bundle gave off branch traces to a lateral bud. At some of the nodes there develops a great swollen mass containing dozens, possibly hundreds, of dormant buds (Pl. V, figs. 10 and 11). This is apparently by the slow growth and multiplication of the buds axillary to the scale leaves of the originally single axillary bud. A similar mass of buds originates at the crown of the hypocotyl from the buds axillary to the leaves of the rosette (Pl. VII, fig. 13; Pl. VIII, fig. 15). These buds constitute an organ reserve which may be called into service in the event of an accident to the more terminal portions of the plant.

If one tugs gently at any bundle of strands derived from the stem of an old, dissected plant, such as that shown in Pl. VIII, fig. 16, he will usually find that a certain number of divisions of the tap-root, bearing in turn lateral roots, will readily tear away from the mass of the plant along with it. Such a detached portion is in one sense a complete individual, with roots, stem and leaves and, if it were planted carefully, there is no apparent reason why it should not continue to thrive. Thus there is always a most intimate connection between certain absorbing, conducting and transpiring elements, and this is preserved through every subsequent dissection of the plant. Since this is the case, it becomes easier to understand why, when a leaf withers, the downward prolongation of its vascular bundles should be of no further service to the plant, and so should be removed from it. In *Mertensia* we have a beautiful argument in favor of the now discarded botanical philosophy that the whole stem and root of the plant are merely an aggregation of basally prolonged leaf traces!

ORIGIN AND SIGNIFICANCE OF THE HABIT OF FISSION

Apparently there is no mention in the literature either of the aberrant behavior of *Mertensia maritima* described in the present paper, or of any abnormality in the secondary thickening of the axis of any other

member of the genus. It is rather surprising that the remarkable structure of a plant so widespread and of such striking appearance as the sea lungwort should remain so little known. No mention of the occurrence of abnormal secondary thickening of the axis of any of the more than 1500 species of the Boraginaceæ is found in either the comprehensive works of Schenck (*20*), Solereder (*22*) or Pfeiffer (*16*), or in any of the shorter papers which have been consulted. The single partial exception to this statement lies in the species *Tournefortia hirsutissima* L., a tropical climber with a woody axis penetrated by narrow plates of secondary phloem, as first described by Crüger (*3*), who does not state whether the cambium is continuous along the sides of the indentations or not. At any rate, we do not have here any inverted secondary bundles, or any complexities of growth at all comparable with those found in lianas of other families and in *Mertensia maritima* in the same family. The very fact that the sea lungwort should have remained so long anatomically unknown, however, makes one extremely cautious about affirming anything definite concerning the family as a whole, with its large number of tropical representatives.

It is of interest to compare the anatomy of the sea lungwort with that of its congener, the Virginia cowslip [*M. virginica* (L.) Link.]. It is hard to imagine two plants of the same genus with more varied habitats, for while the former thrives on stony, exposed seacoasts, the latter prefers sheltered, wooded valleys of the interior, where it grows in deep, rich, alluvial loam. The erect stems arise from tap-roots, which, while young, are usually spindle-shaped and often forked, but in age may become very irregular (Pl. IX, fig. 17). These tap-roots, like those of *M. maritima,* contain no fibres in wood or bast, but merely the vascular elements imbedded in succulent parenchyma. The outer secondary cortex is cut off by a periderm every spring, and in older, larger tap-roots the central xylem is also cut out by periderm, but there is considerable irregularity in this respect. This tissue then decays and leaves a central cavity. The largest tap-root examined by me measured 4 cm. in diameter at its widest part, and contained a central cavity 2.5 cm. in width. Once the central cavity is formed, a new ring of periderm cuts off the oldest surviving xylem at the renewal of growth every spring, at the same time a concentric ring of periderm cuts off the older phloem on the outside. Rarely the periderm may penetrate along the primary parenchyma rays and after the tissue which it cuts off has decayed away, the interior cavity communicates with the exterior.

Fig. 28 shows a cross section of the tap-root which of all those examined bore the greatest resemblance to *M. maritima*. It was split into two distinct portions for a short length only. The plant was collected in the spring, and the xylem and phloem most recently cut off were still fresh. The tissues cut off in the previous spring, now decayed beyond recognition, surround the root and fill the central cavity, and

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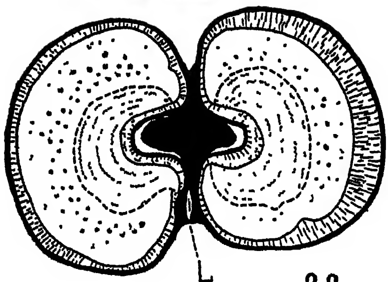

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FIG. 27.—Cross-section of a primary division of a vigorous stem, collected in early June, at the beginning of its third growing season, showing its secondary fission at this level into five strands. Symbols as in Figs 2-5 (Camera lucida, × 10)

FIG. 28.—Cross-section of that root of *Mertensia virginica* which most resembled *M. maritima* in its mode of splitting. From material collected in Baltimore County, Maryland on May 22nd. Older, dead tissue is shown in black, tissue just cut off by periderm is indicated by radial lines, cambium by broken line, L=lateral root (× 2).

in the figure are shown in solid black. It will be seen that in neither half has the cambium closed about the interior of the xylem to form a complete ring. The root in question bears more resemblance to a root of *M. maritima* which has undergone "sporadic" fission than to one which has passed through the winter and undergone "universal" fission in its second spring. In the cutting off of older tissues, however, we find an adumbration of the habit which is carried to its ultimate expression in *M. maritima*.

Until the time of fission, there is nothing unusual about the anatomy of the axis of *M. maritima*. It closely resembles that of *M. virginica*, surprisingly so considering the diverse habitats of the two plants and, as we have already seen, agrees closely in its general plan of structure with the herbaceous European Boraginaceæ as we know them through the work of Jodin (*10*).

The classic work on the split rhizomes of perennial herbaceous plants is that of Jost (*11*), and a brief summary of the whole subject, carrying the literature concerning it down to date, is found in the recent monograph of Pfeiffer (*16*). Splitting of the rhizome regularly occurs in *Gentiana cruciata* and allied species, *Corydalis nobilis, C. ochroleuca* and other Fumariaceæ, *Aconitum Lycoctonum, Delphinium elatum* and *D. scaposum, Salvia pratensis, S. silvestris* and *S. austriaca* and *Sedum aizoon*. In America the subject has not received so much attention as in Europe, and *D. scaposum*, described by Kingsley (*13*), is the only American species included in the list above. Of interest in this connection is the method of vegetative multiplication through the splitting of the root and basal portion of the stem described by Dastur and Saxton (*4*) for *Crotalaria buhria*.

The essential feature of the behavior of all hitherto described cases of split rhizomes is the isolation from the portion of the plant destined to remain alive of all vascular tissues—xylem and phloem—most directly connected with the annual stem and leaves of the plant. Usually this first occurs in the plant's second year, after these organs have withered. The process is repeated year after year, always with the result that the oldest remaining xylem and phloem are removed, since the organs they served are no longer in existence. In *Gentiana, Aconitum, Delphinium* and *Salvia* the useless portions are cut off from the living by a periderm, while in *Corydalis* the separation is brought about by the suberization of the walls of preexisting cells. When the dead tissues have decayed away, the living portions remain as distinct longitudinal strands. The first dissection of the rhizome is a result of the isolation of the cauline bundles (the fusion bundles of Jost), which are held together by the vascular connections of the lateral buds. In *Gentiana cruciata* the opposite, decussate leaves are supplied by four cauline bundles alternating with the four ranks of leaves, and in the dissection of the rhizome these remain as four distinct pillars, pairs of which are straddled by the two traces of each of the lateral buds, as was described long ago by Irmisch (*9*). The leaf-insertions are very close together, and the presence of the lateral bud often crowds to one side the insertion of the

leaf next above, a circumstance which gives a spiral twist to the orthostichies and leads to a complication of the form of dissection. In both *Corydalis* and *Aconitum* the common bundles (leaf traces) are cut away from the tissues which remain alive, and only the cauline bundles become a permanent portion of the plant—a condition we find exactly paralleled in *Mertensia.* Through the forking of the rays of vessels, and the disintegration of the parenchyma rays which arise between them, the strands representing the cauline bundles are further subdivided.

The roots of *Aconitum, Delphinium, Corydalis, Gentiana* and *Salvia* are split as well as the rhizomes. In *Gentiana cruciata* the vessels of the secondary xylem lie in rays which alternate with rays consisting of parenchyma alone, much as has been described for *Mertensia.* The cambium across the parenchyma rays becomes inactive, also as in *Mertensia.* Along these rays the periderm which isolates the central portion of the xylem becomes confluent with the periderm which cuts off the older phloem, and in this manner the root becomes split into distinct strands. In the diarch roots of *Corydalis* broad parenchyma rays continue the radii of the protoxylem points. The cambium across these rays dies out, and the starch disappears from these cambium cells, from the rays themselves, and from the outer phloem and the inner xylem. The cells of these rays and the older xylem and phloem lose their protoplasmic contents and their walls take on a brown color. During the course of the summer they decay away, leaving the root divided into two portions, which are bound together by the lateral roots, or by their separate strands after these in turn have become divided, as we have described for *Mertensia.* In succeeding years each half of the root is again repeatedly split by the death and decay of the cells composing the secondary parenchyma rays between the forking wedges of vessels and sieve-tubes. The formation of well defined annual rings in this species makes it possible to determine that during the winter the vessels and sieve-tubes of a single growing season only are present. The diarch roots of *Aconitum* become divided in almost exactly the same manner as *Corydalis,* except that in the former periderm separates the dead parts from the living. The triarch, tetrarch and pentarch roots of this plant may undergo a primary division into a larger number of parts.

In *Mertensia,* as well as the species described by Jost, the dissection of the subterranean parts into externally separate strands is a result of the removal of the xylem and phloem directly connected with the dead annual parts of the plant. This pruning away of older tissue is, if anything, more severe in *Mertensia* than in any of the other described

plants with dissected rhizomes and roots, for, *at the very outset of any growing season, all but the merest fringe of the products of the cambium during the previous growing season is cut away, and never more than one "annual ring" of active xylem and phloem is preserved.* Although their method of procedure is radically different from that of most other plants, the behavior of herbs with split rhizomes and roots is the same in kind as that of other perennial species which lack this striking peculiarity. The abscission of effete organs and tissues is a phenomenon so common in the plant kingdom and so well known that specific instances of it need hardly be mentioned here [see Skutch (*21*) pp. 388-89]. As Jost justly remarks, the species described by him stand midway between those perennial herbs which die away at the basal end in measure as they produce new shoots at the apical, and those which preserve and thicken the primary root and rhizome at the same time that they produce new organs. With the latter they have in common the retention of organs, with the former the withering of the oldest tissues. And even in trees which in old age are generally hollow, as the willow, we find a certain analogy to these herbs with dissected rhizomes.

In spite of these points of agreement with other plants with dissected organs, *Mertensia* surpasses in complexity any of the other species we have just discussed. In these the cambium does not close about the inner side of the bundle of vessels left by the dissection of the root or stem, and accordingly no secondary vascular bundles of inverse orientation are ever formed. Although certain portions of the cambium and its derivatives disappear from the scene, the remainder of the cambium ring goes on to produce phloem externally and xylem internally, and behaves, in all essential features, almost as though this interruption of its continuity had never occurred. There is no new formation of cambium, no production of secondary xylem and phloem in abnormal relation to each other. For this reason Pfeiffer (*16*) denies that these plants exhibit "Abnormal growth in thickness" as defined by him in his monograph of that title. The formation of a closed cambium ring in each strand and the production of bundles of inverse orientation remove *Mertensia* from the category of *Gentiana* and *Corydalis* and place it on a par, anatomically, with the abnormally thickened lianas. A cross-section of the bundle of strands which results from the repeated dissection of a single stem or root of *Mertensia* exhibits a complexity in gross structure equalled only by some of the most advanced climbing stems of the Leguminosæ, Malpighiaceæ, Sapindaceæ, etc. It is of interest to compare our Fig. 10 with Pl. III, fig. 30b, Pl. IV, fig. 12b, and

Pl. X, fig. 130, for example, in Schenck's (*20*) monograph. The methods by which the structures delineated in these figures arose are in each case different in detail, but the end results are certainly comparable in complexity.

It is impossible to find an exact parallel to the behavior of *Mertensia* among climbing plants because in the latter the formation of secondary vascular bundles is not associated with the dying away of the older tissues. The cable structure which adapts the stems of these plants to the mechanical demands made upon them is secured by the breaking up of the hard xylem into distinct strands imbedded in the softer phloem, without the necessity that these strands be externally distinct; and lianas, just the contrary to *Mertensia,* are characterized by the long-continued efficacy of their conducting elements. In many lianas, however, the stem does at length become divided into externally distinct strands (e. g. *Cassia* among the Leguminosæ and *Sabicea* among the Rubiaceæ [Cruger (*3*)], *Serjania* among the Sapindaceæ [Schenck (*20*)]. *The formation of a dilatation parenchyma in which a cambium arises* is a peculiarity which allies *Mertensia* in the first degree with many lianas, we need mention only *Stigmatophyllon* and *Tetrapteris* (Malpighiaceæ) and *Serjania* [Schenck (*20*)]. In *Serjania piscatoria,* for example, if we leave aside the irregular arrangement of the primary bundles, and the formation of secondary bundles in the peripheral tissues, and consider only the central xylem mass, we find a certain parallel, albeit of the most general sort, to *Mertensia.* Through the dilatation of the cells of the medullary rays, the sinuses of the originally deeply lobed cambium are prolonged inward until they enter the pith, in the outer portion of which a dilatation tissue is also formed. A cambium ring finally encloses each of the segments, usually four, into which the woody cylinder is split, and produces xylem on the interior of the ring and phloem on the exterior, that is, toward the sinuses and the central pith (see Schenck, Pl. V, fig. 52b).

Since *Mertensia* displays, in common with lianas, a highly developed cable type of structure, it seems not unnatural to look for a common explanation of the evolution of the habit. It is a far cry from the stems of lianas pendent from the boughs of tropical trees to the stems and roots of *Mertensia* buried beneath the stones on arctic and subarctic seacoasts. Both, however, are subjected to mechanical stresses of kinds not encountered by most other plants. The liana, in the views of Schenck (*20*) and Haberlandt (*7*), has developed the cable structure as that best fitted to withstand the torsions, flexures and tugs to which it is

subjected and, if it be a twiner, at the same time adapt itself to the often considerable radial stress it experiences as the tree about which it is coiled grows in diameter. Such a structure, on the other hand, would be impracticable in any plant which depends for its place in the sun upon the rigidity of its own stem. The root or buried shoot of a plant of *Mertensia* growing in shingle must, as it increases in diameter, force aside the stones which surround it for its entire length. The subterranean organs of practically every plant come into contact with occasional stones, but those of *Mertensia* are completely encased in them. Pushing against these stones, they are subjected to considerable and *unequal* radial stresses. The tap-root of *M. virginica,* at home in alluvial loam, would seem to us utterly lost in the stony bed of a sea lungwort. But the latter plant, like the former completely devoid of mechanical elements in its subterranean parts, is able to adapt itself to the irregularities of the stones by flattening out the constituent strands of the cable where need be, as one often discovers on digging up the plant. Furthermore, a local injury inflicted by crushing against the rocks is not so likely to prove serious where an organ is divided into distinct strands, as when it is entire and solid.

We have said nothing about strains to which the plant may be subjected through the shifting of the shingle by the waves, because on Mt. Desert Island we have seen little evidence of its occurrence. As Carey and Oliver (*2*) have pointed out, the movement of the shingle is entirely confined to the surface layers and, where plants have been buried by the rolling of shingle higher up on the beach, it has been apparently without the disturbance of the strata in which the plant was already established. On other shores, however, it is conceivable that the plants of *Mertensia* may be alternately covered and uncovered, in which case great flexibility, such as is found in the cable type of structure, would be of much service. This point deserves further observation.

Assuming the survival value of the stranded structure of *Mertensia maritima,* and recognizing a foreshadowing of its habit of cutting off the older tissues by periderm in *M. virginica,* which we may take as in this respect a more primitive type of the genus, we could conceivably account for the present structure of the plant by the natural selection of random variations. Opposed to this view is the question of the direct influence of mechanical stresses on the morphology of the plants, the answer to which here, as in the case of lianas, we can hardly surmise.

Another aspect of the problem which deserves consideration is that of size. One thinks of Bower's suggestive paper on "Size, a Neglected

Factor in Stelar Morphology" (*1*). With the increasing diameter of a solid organ, the aeration and nutrition of its central tissues becomes more difficult. One manner in which the difficulty may be overcome is by the splitting of the organ into distinct strands, as occurs in *Mertensia.* Large size, with the increased possibility of the production of large numbers of seeds by a single individual, is of great value to a species like *Mertensia,* which seems to thrive best on stretches of shore (up-building shingle), where the establishment of seedlings is most hazardous (see above, p. 8). While it might not seem difficult for a small plant of *Mertensia* to overcome the mechanical difficulties of life in the shingle without becoming dissected, it is hard to imagine how a solid, undivided tap-root or rhizome, upright as is the fixed habit of the plant, could become large enough to support at its crown 250 flowering stems, without experiencing great obstacles in making the essential mechanical adjustments to its environment. Then, too, although the shingle is of its very nature a well aerated substratum, it must be remembered that *Mertensia* is provided with no lentecils, and no radially elongated cells forming a true medullary ray, so that the aeration of such a mass of necessarily very active tissue would prove difficult.

Other plants, lacking the habit of *Mertensia* we have just described, exist side by side with it on the shingle. These are plants of different growth forms and different affinities, that started their evolution as shingle beach plants with different structures and different hereditary constitutions, so we can judge little of the value to *Mertensia* of any structure presumably an adaptation by its failure to appear in these others. Here as elsewhere we see that plants with their plastic organization solve the same problem of adaptation to life in a particular habitat in many diverse ways. The sea lungwort's solution is only one of them, perhaps the best possible for a species with its particular phylogenetic background, but of no universal validity.

While working over the anatomy of *Mertensia,* I was interested in seeking evidence of the applicability of the views of Priestley (*18, 19*) on the rôle of the endodermis in the origin of periderm. Not only do we have the formation of periderm beneath the endodermis of the root and the subterranean portions of the shoot, but also its production in the peripheral portion of the pith of the etiolated shoot, sometimes in the central xylem of the tap-root, and around each strand formed by the dissection of root and stem. Briefly, Priestley holds that it is the accumulation of solutes behind the relatively impermeable barrier which the endodermis forms, especially after its tangential walls have become

suberized, or it has entered the "secondary stage," to use his own terminology, which is responsible for the beginning of meristematic activity in the pericycle. We saw that in both the hypocotyl and the etiolated shoot the endodermis had entered the secondary stage at the time of the first phellogenic divisions in the pericycle. In the pith of the etiolated shoot also, the suberization of a layer of cells near its periphery was accompanied by the origin of a phellogen in the next layer exterior to it, that is toward the vascular tissue and the course of the solutes carried down from the leaves. In the aerial stem the endodermis remains in the primary stage, its tangential walls do not become suberized, and in the pith the walls of the layer of cells corresponding to those which become suberized in the etiolated stem remain unsuberized. Here no phellogen is formed, either in the pericycle or in the pith. We have also seen that in the dissection of the subterranean organs the walls of a layer of cells surrounding each new strand become suberized before a definite phellogen is formed. There is a possibility that some decrease in the permeability of the cells of this layer occurred even before the origin of the dilatation parenchyma and was responsible for it, but this point was not specifically investigated. In another suggestive paper, Priestley (*17*) states that there is much evidence for the view that "the main morphological and structural features of etiolation are determined by a redistribution of growth at the shoot apex, consequent upon the greater difficulty experienced by the meristem in drawing nourishment from the vascular supply because, when growing in the dark, the walls between vascular strands and meristem are rendered relatively impermeable by the retention in them of the protein and fatty substances that form the surface of the protoplast." Probably it is a similar difficulty in drawing nourishment from the vascular strands that is responsible for the cutting out of the pith of the etiolated shoot of *Mertensia*—the fatty substances accumulate in a layer relatively near the vascular bundles, with the result that a periderm arises in the next layer to the exterior. And we can only surmise how far the difficulty of obtaining nourishment at a distance from the *active* vascular elements is responsible for the whole process of dissection as we have described it in *Mertensia*.

SUMMARY

1. *Mertensia maritima,* an herbaceous plant of high northern latitudes of both hemispheres, grows on shingle and sandy beaches. The shingle bar, with its peculiar restrictions as to soil and water, forms a favored habitat.

2. On Mt. Desert Island, Maine, the seeds germinate about the first week of June. As a result of the dimness of light in the shingle in which they germinate, most of the seedlings show the typical aspect of etiolation. Seedling mortality is very high.
3. The root and the lower portion of the hypocotyl are exarch and diarch. Only in its upper quarter does the hypocotyl contain a pith.
4. The hypocotyl and primary root of the seedling develop into a fleshy tap-root, which during the first summer bears a rosette of leaves at its crown.
5. No fibres are formed in the secondary xylem or phloem of the root. The vessels and sieve-tubes occur only in sectors which alternate with broad parenchyma rays. These sectors fork repeatedly.
6. By the middle of August, the cambium has become relatively or completely inactive where it crosses the parenchyma rays. The oil globules, which are the principal food reserve of the plant, disappear from these rays and from the outer secondary cortex.
7. During the first summer, the central xylem of the tap-root is sometimes cut off from the younger tissue by a periderm, and then it disintegrates. The cambium is produced inward along the edges of the primary parenchyma rays, and sometimes forms a closed ring around each of the two masses of remaining secondary xylem. By the extension of the central periderm along the primary parenchyma rays until it meets the outer periderm surrounding the organ, the tap-root and some of the most vigorous lateral roots are split in two. This form of fission is of sporadic occurrence.
8. In the spring of the second year the cambium produces a number of very wide vessels which contrast sharply with the narrow vessels formed at the end of the preceding growing season. As a result of the return to the meristematic state of the parenchyma cells between the latter, a dilatation parenchyma is formed.
9. The newly formed xylem and phloem of a single wedge, or of a group of adjacent ones together, is cut off by periderm from all of the older tissue. In the xylem, the periderm arises at the inner edge of the dilatation parenchyma.
10. The cambium is produced inward around the edges of each group of spring vessels and across the dilatation parenchyma, forming a closed ring around the newly produced xylem of each sector of vessels, or group of adjacent ones.

11. By the decay of the older tissue cut off by the periderm, the tap-root becomes divided into longitudinal halves, each of which is a network of anastomosing strands.
12. The intraxylary cambium of the stronger strands originates new vascular bundles of inverted orientation in respect to the organ in its entirety.
13. In the following spring the newly formed xylem and phloem of each wedge in the primary strand is isolated by periderm to form secondary strands. This process is repeated year after year until a thick cable of strands is formed.
14. In its second year the perennating tap-root sends out decumbent aerial flowering shoots. These die off in the autumn, but are renewed in the following year from the mass of dormant buds which arises at the crown of the tap-root.
15. When a plant which has been buried beneath the shingle during the winter storms becomes active again in the spring, it sends out shoots which push up through the overlying stones and show the usual symptoms of etiolation. The portions of these shoots buried in the shingle, differing fundamentally from the aerial portions in their anatomy, constitute an addition to the perennating portion of the plant.
16. There are five common and five cauline bundles. At the apex of the shoot the common bundles contain several times as many differentiated xylem elements as the cauline. After the beginning of cambial activity the cauline bundles are very considerably thickened by the formation of numerous conducting elements, while practically none are added to the common bundles. The cambium of the common bundles has generally become inactive by the middle of August, at a time when that of the cauline bundles is still actively dividing. This difference in the behavior of the two classes of bundles is of the utmost importance in determining the future structure of the stem.
17. In the etiolated portion of the shoot, there is a reduction of the number of distinct bundles to six, five or rarely four, although the phyllotaxy does not change.
18. In the etiolated portion of the shoot, the endodermis enters the secondary stage and a periderm, arising beneath it, cuts off the cortex. At the same time, the pith is cut off from the vascular tissue by a periderm which originates outside of a layer of medullary cells which become suberized.

19. In the following spring, the newly formed xylem and phloem of the cauline bundles is separated by a periderm from all surrounding tissue. With the decay of the older tissue, these form externally distinct strands, the course of which is determined by the primary arrangement of bundles in the stem. Only those cauline bundles which lead to actively growing lateral buds are preserved.
20. The subsequent behavior of each strand resulting from the dissection of the stem closely resembles that described for the root. It is not possible by an examination of the cross-section to distinguish one from the other.
21. In *Mertensia virginica* we find a foreshadowing of the behavior described for *M. maritima.*
22. *Mertensia maritima* far surpasses in complexity any hitherto described herbaceous plant with split rhizomes and roots. The complexity in form of the cable of strands resulting from the repeated dissection of a single axial organ finds a parallel only in the stems of certain highly specialized lianas.
23. As in the case of lianas, the cable-like structure of *Mertensia* seems to be an adaptation to the peculiar stresses, not encountered by the great majority of plants, to which its mode of life subjects it. Specifically, these stresses are found in the unequally distributed pressure of the stones in which it grows.
24. The habit of fission also permits the attainment of a larger size than would seem possible in the absence of this habit. Since the establishment of seedlings is so difficult, the large size and the consequent great seed production by the individual is at a premium.
25. The views of Priestley on the rôle of the endodermis in cork formation, and on the distribution of growth in etiolated shoots, find confirmation in the present study.

BIBLIOGRAPHY

Bower, F. O.

(*1*) 1921. Size, a neglected factor in stelar morphology. Proc. Roy. Soc. Edinburgh, XLI, Pt. 1, No. 1, pp. 1-25.

Carey, Alfred E. and Oliver, F. W.

(*2*) 1918. Tidal lands, a study of shore problems, pp. xiv + 284. London.

Crüger, Hermann

(*3*) 1851. Einige Beiträge zur Kenntniss von sogenannten anomalen Holzbildungen des Dikotylenstammes, III. Bot. Zeitung, IX, pp. 465-473.

DASTUR, R. H. and SAXTON, W. T.
(4) 1921. A new method of vegetative multiplication in *Crotolaria buhria*. Ham. New Phytol., XX, pp. 228-233.

FERNALD, M. L.
(5) 1921. The Gray Herbarium Expedition to Nova Scotia, 1920. Rhodora, XXIII, pp. 284-300.

GRAY, ASA
(6) 1878. Synoptical Flora of North America, II, Pt. 1, p. 200. New York.

HABERLANDT, G.
(7) 1924. Physiologische Pflanzenanatomie, 6th Ed., pp. xvii + 671. Leipsig.

HILL, T. G. and HANLEY, J. A.
(8) 1914. The structure and water-content of shingle beaches. Journ. Ecol., II, pp. 21-38.

IRMISCH, TH.
(9) 1849. Einige Bemerkungen über *Gentiana cruciata, ciliata* und *germanica*. Bot. Zeitung, VII, pp. 1-11.

JODIN, HENRI
(10) 1903. Recherches anatomiques sur les Boraginées. Ann. de Sci. Nat. Bot., Ser. 8, XVII, pp. 263-344.

JOST, L.
(11) 1890. Die Zerklüftungen einiger Rhizome und Wurzeln. Bot. Zeitung, XLVIII, pp. 433-445, 453-462, 469-480, 485-493, 501-512.

KANE, ELISHA KENT
(12) 1856. Arctic Explorations (Vol. II, Appendix XVIII) Philadelphia.

KINGSLEY, M. A.
(13) 1911. On the anomalous splitting of the rhizome and root of *Delphinium scaposum*. Bull. Torrey Bot. Club, XXXVIII, pp. 307-317.

OLIVER, F. W.
(14) 1912. The shingle beach as a plant habitat. New Phytol., XI, pp. 73-99.

OSTENFELD, C. H.
(15) 1908. The Land Vegetation of the Faeroës. Botany of the Faeroës based upon Danish investigations, III, pp. 867-1027.

PFEIFFER, H.
(16) 1926. Das abnorme Dickenwachstum. Linsbaur's Handb. der Pflanzenanatomie, IX, pp. xii + 272, Berlin.

PRIESTLEY, J. H.
(17) 1926. Light and Growth II. On the anatomy of etiolated plants. New Phytol., XXV, pp. 145-170.
(18) 1926. The relation of cork formation to the endodermis in the shoot of the dicotyledon. Proc. Leeds Philosophical Soc. (Scientific Sect.) I (Pt. 3), pp. 123-135.

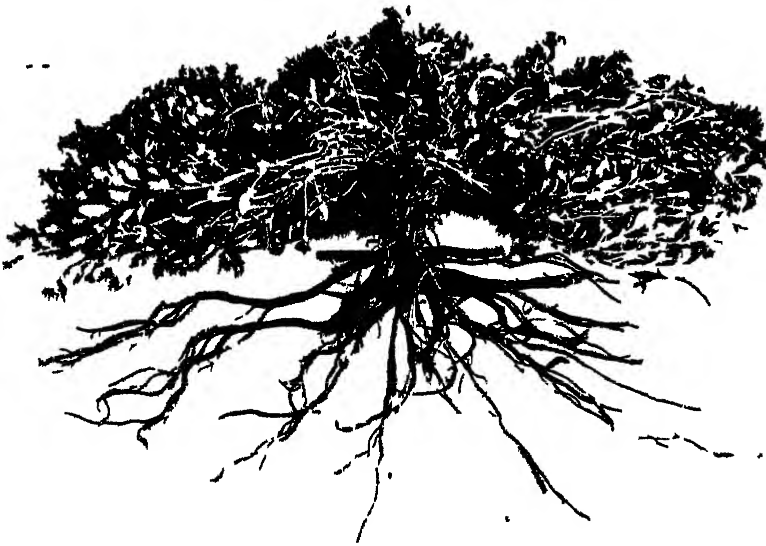
PRIESTLEY, J. H. and NORTH, EDITH E.
(*19*) 1922. The structure of the endodermis in relation to its function. New Phytol., XXI, pp. 113-139.

SCHENCK, H.
(*20*) 1893. Beiträge zur Anatomie der Lianen, pp. xiv + 271. Jena. In Schimper's Botanische Mittheilungen aus den Tropen, Heft 5.

SKUTCH, ALEXANDER F.
(*21*) 1927. Anatomy of leaf of banana. Bot. Gaz., LXXXIV, pp. 337-391.

SOLEREDER, HANS
(*22*) 1908. Systematic Anatomy of the Dicotyledons. Trans. by Boodle and Fritsch. 2 vols., pp. xii + 1182. Oxford.

FIG. 1.—The shingle bar south of Manset, Mt. Desert Island, Maine. Seven plants of *Mertensia* are growing in the field of view near the top of the bar. The *Triglochin maritima* marsh which lies behind the beach may be seen at the extreme left.



2

FIG. 2.—A vigorous plant about [illegible] years old dug up and photographed June 11, 19[illegible]. The ruler beneath the tap root is [illegible]0 cm. long. This plant, which had been buried 8 cm. by the shingle since its establishment, bore [illegible]60 stems.

FIG. 3.—The plant shown in Pl. 1, fig 2, *in situ* in the area included in Pl. I, fig. 1 The ruler in the foreground is 30 cm. long, and the decumbent stems, although not yet full grown, covered an area 120 cm. in diameter.

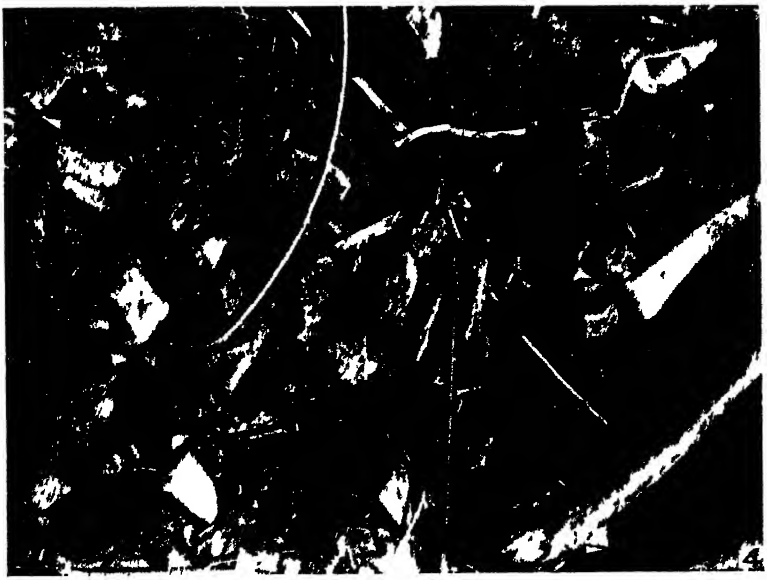


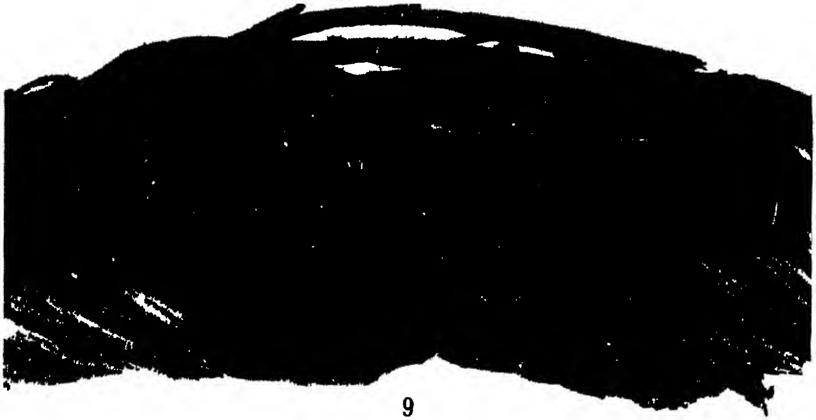
FIG. 4.—Young shoots of a plant, covered by shingle during the previous winter, growing up through the shingle and mixed debris on a beach south of Manset, June 11, 1928

FIG. 5.—A one-year-old plant which had been slightly buried during the preceding winter. Notice the shrunken condition of the tap root. Photographed June 8, 1928. (× about 1.)

FIG. 6.—A two-year-old plant which has undergone one period of fission, photographed on June 8, 1928. (× about ¼.)

FIG. 7.—A four-year-old plant which had been buried each winter so that at the time it was dug up the collet was 40 cm beneath the surface. The pencil points to the collet; the ruler is 30 cm long. Compare this plant with the much larger plant shown in Plate I, fig. 2, which is a year younger but had not been so deeply buried. Photographed June 5, 1928.

FIG. 8.—A plant which had been buried by the shingle and was uncovered again during the winter before the picture was taken. The new shoots arise from near the base of an old several times dissected stem. Photographed June 5, 1928. (× about 1/5.)



9

FIG. 9.—A several-times-dissected root collected August 19, 1925. At one cross-section of this root 60 distinct strands were counted. Notice the spiral trend of the strands (× about 2).

10

FIG. 10—A dissected stem with its branches, to show the swollen masses of dormant buds at some of the nodes. Collected August 19, 1925 (× about 1 2).

11

FIG. 11.—Another stem like that shown in Fig. 10. (× about 1/2).

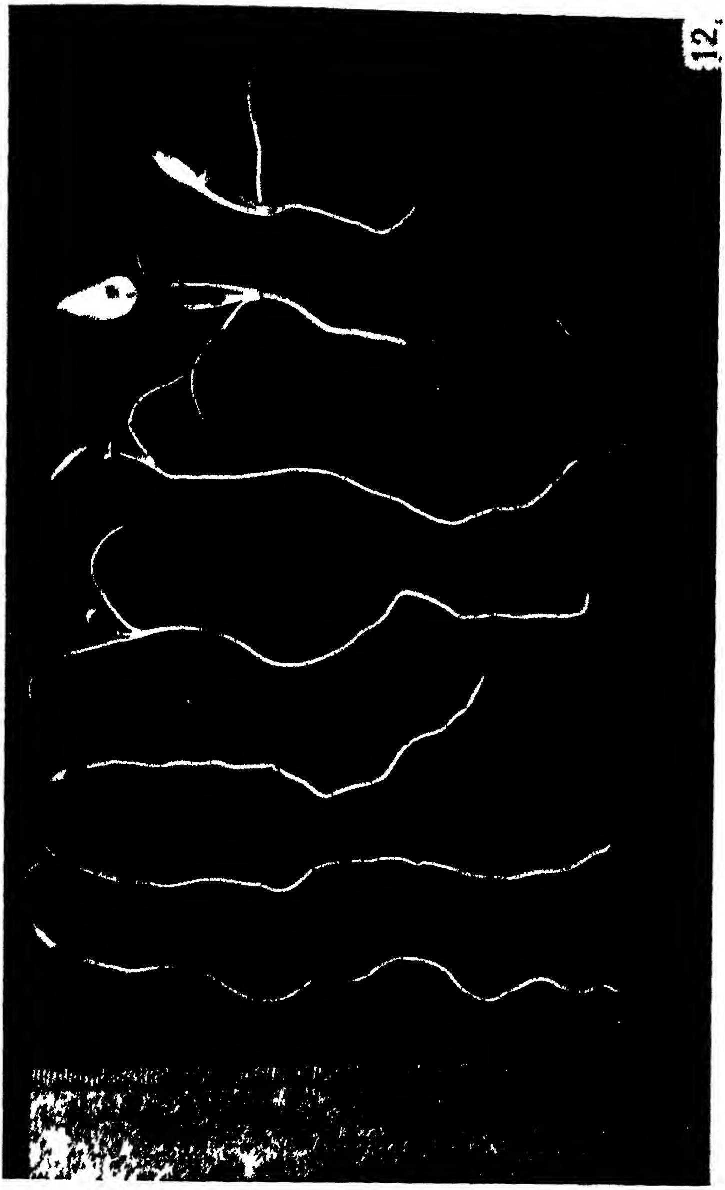


FIG. 12.—Seedlings of *Mertensia*, all collected on June 3, 1928. The ruler to the left is graduated in centimeters.

13

FIG. 13.—The tap root and bases of shoots of a plant in its second summer. Notice the buds clustered about the bases of the shoots at the crown of the hypocotyl. Collected August 19, 1925. (about natural size).

14

FIG. 14.—A plant which has been buried 35 cm. since its establishment. The vigorous branch at the right grew out from the collet and pushed up through the shingle during the preceding spring. The 37 cm. length of this shoot which was covered by the shingle survived the winter and is now undergoing its first dissection (cf. Text-fig. 15). Notice, among the mass of new shoots sprouting up from the branches to the right, the blackened bases of last season's aerial shoots. Photographed June 5, 1928. (× about 1/7.)

FIG. 15.—The tap-root of a plant in its fourth summer. Text-fig. 10, a cross-section made of the same hypocotyl after it had been photographed, shows that it had been dissected on three separate occasions and consisted, at the level of this figure, of 74 distinct strands. Notice the massed buds at the crown. Collected August 19, 1928. (× about 1.2.)

15

FIG. 16.—The perennating bases of the stems of a four or five-year-old plant growing on the shingle bar at Bass Harbor (see text, p. 6). These stems have together been dissected into hundreds of strands. The tap-root is shown at the very bottom of the figure, and the bases of the flowering stems of the present season are clustered at the top. The depth of burial of this plant since its establishment was about 30 cm. The ruler at the right is 12 inches long. Collected August 19, 1925.

17

FIG. 17.—The basal portion of a plant of *M. virginica* collected in Baltimore County, Maryland, May 22, 1928. A split in the outer secondary cortex of the root, which is being cut off from the living tissues by periderm, is plainly visible. (× about 1).

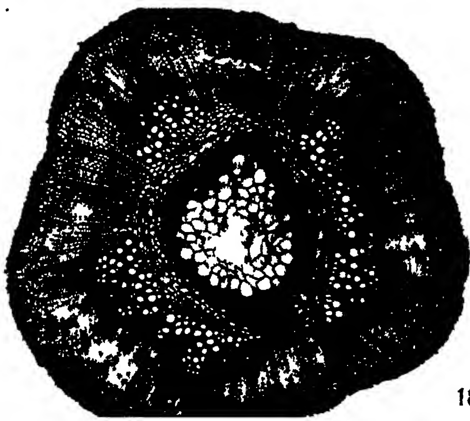


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FIG. 18.—A cross-section of the buried base of a shoot of *M. maritima* in its first summer. For explanation see text pp. 30, 31, 33. (× about 25.)

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FIG. 19.—A halved root of *M. virginica*, showing the internal cavity. The periderm which cuts off the outer secondary cortex is plainly visible in the figure; that cutting out the oldest extant xylem is not so distinct. Collected May 22, 1928 (× about 2/3).

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TONIC AUTOMATISM IN THE STOMACH OF THE MONKEY AS THE DETERMINING FACTOR IN THE TYPE OF ITS MUSCULAR RESPONSE

BY

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TONIC AUTOMATISM IN THE STOMACH OF THE MONKEY AS THE DETERMINING FACTOR IN THE TYPE OF ITS MUSCULAR RESPONSE.*

By THOMAS L. PATTERSON

CONTENTS

INTRODUCTION

Since the celebrated experiments of Beaumont (1833) on the stomach of Alexis St. Martin, nearly a century of experimentation in gastric physiology has not solved completely the problem of the inner controlling factors concerned with the movements and tonus of this organ. Many factors which might influence the process, as nervous, chemical or "hor-

* The publication of this paper has been made possible through a grant from the income of the Ralph Winfred Tower Memorial Fund.

mone," pressure and temperature have been investigated, but it has always been a question how nearly the conditions approach those of normal activity. In higher animals the movements of the empty stomach (hunger peristalsis) are periodic in character and more vigorous than the peristaltic movements of digestion which normally commence a few minutes after the entrance of food into the stomach and continue until all the nutrient material in the form of chyme has been passed on into the small intestine.

The character of the periodic and motor activity of the empty stomach in man has been reported (Carlson, 1912). Since the motor activity in the stomach of the dog (Carlson, 1913; Patterson, 1915) exhibits certain variations from that of the human, the monkey was selected for this experimental investigation because of the ancestral relationship which it is assumed to bear to man in the evolutionary process of animal development. This so-called relationship would be suggestive of the closest parallelism existing between the gastric activities of these two Primates. Furthermore, Carlson (1913) has shown that in the dog and in man the movements of the empty stomach may be modified by psychic stimuli, though only in the direction of inhibition and that in the dog they continue even when the stomach has been isolated from the central nervous system by section of the vagi and splanchnic nerves. After such section inhibition of tonus and contractions may still be obtained by stimulation of the gastric mucosa, but it is diminished both in intensity and duration. Cutting the vagi leaves the stomach in a permanently hypotonic condition (Carlson, 1913). It is evident that the central nervous system acts merely as one of the regulators of this reflex mechanism but for how much of the regulation the cerebrum is responsible and what part is played by the midbrain and medulla is still open for further investigation. Therefore, it is the purpose of this communication to present data in some detail which confirms and extends the findings on gastric behavior in man.

In view of the fact that the literature on the nature of the sensation of hunger is exhaustively reviewed in Carlson's book (1916), the reader is referred to that source for a further general consideration of the problem.

Acknowledgments

I desire to express my thanks to all those who have so kindly assisted in the carrying out of the various phases of the investigation herein re-

ported, and especially to Doctors L. W. Rubright and R. J. Scott (former students), Miss Jessie Illenden and Mr. J. A. Gijsbers, who have given so generously of their time and energy in the execution of this problem.

EXPERIMENTAL PROCEDURE

Animal Material

The experiments forming the basis of this report were made on Javanese and Ringtail monkeys (*Macacus irus** and *Macacus rhesus*) and one baboon (*Cynocephalus anubis*). Twenty-nine healthy young animals were used. The Javanese monkeys were obtained from an animal importer at San Francisco and the others from importers in New York.

The Javanese monkeys were employed chiefly in the earlier experiments in a study ot the movements of the empty stomach. Although so-called tamed monkeys were purchased, none were sufficiently trained for the particular type of experimentation in question. In fact, unlimited patience was required during the many weeks of preliminary training and even then it was found impossible to tame some of the animals after employing every conceivable means.

Experiments on Normal Animals

The animals trained to permit handling were then operated on and provided with gastric fistulæ in the fundus of the stomach after the method of Carlson (1913) on dogs. In from five to seven days the wound was sufficiently healed to permit the recording of the gastric hunger contractions by the balloon method with the animal lying quietly in the lap of an attendant (Fig. 1).

Since monkeys are so deeply concerned in what goes on round about them, it was necessary either to partition off a corner of the laboratory for the animal and the attendant or place them in an adjoining room with the rubber tubes and electric signaling wires passing through the wall, so as to exclude the activities of the kymograph operator. So observant are the animals that even the crawling of a fly on the wall or ceiling will attract sufficient attention to lead to restlessness and interference of the

* A communication from Tracy I. Storer, Inspector of Foreign Birds and Mammals, Port of San Francisco, U. S. Department of Agriculture, Bureau of Biological Survey, reads as follows: "Your request for information on the Javanese Monkey is not an easy one to answer. There is a great deal of doubt in the minds of the people who have worked on the monkeys of that group as to just what name should be applied. I think that the name *Macacus irus* or *Pithecus irus* is the one commonly applied to this form. In any event, the use of this name will be as nearly correct as any which you can use."

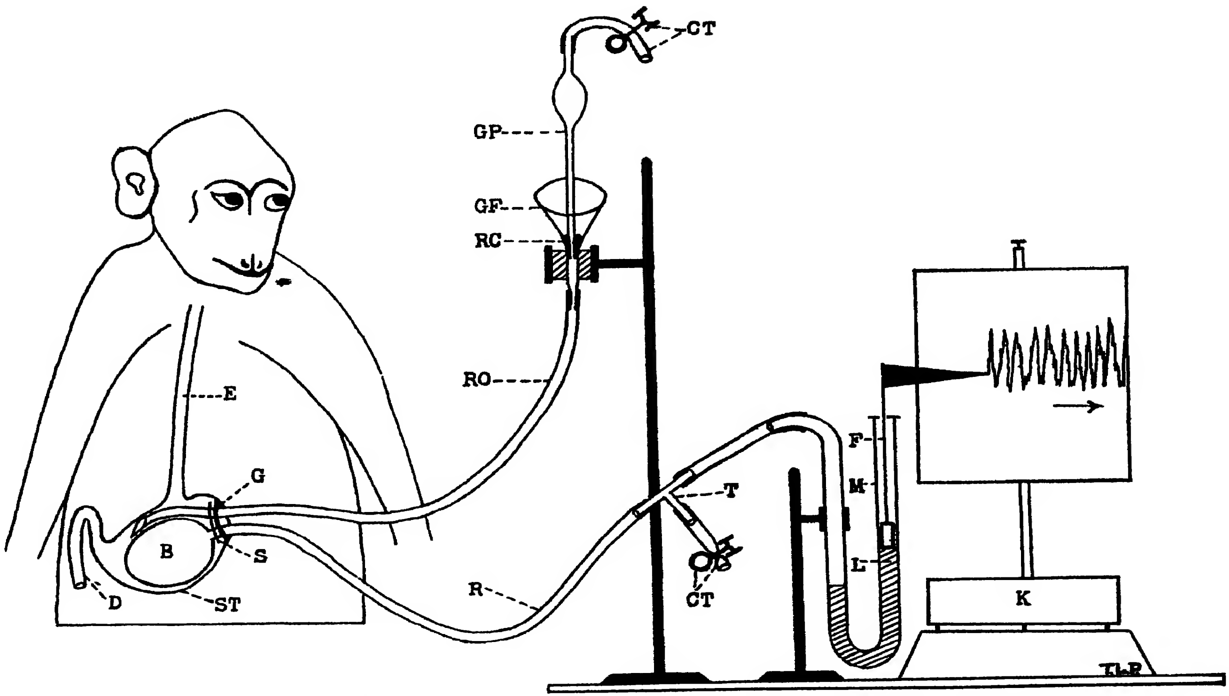


FIG 1.—Diagram showing method of recording gastric motility and the effect of inhibitory substances on the monkey's stomach K, kymograph F, glass float with recording flag. M, manometer. L, manometer liquid (water) T. glass T-tube for inflation of balloon. R, rubber tube connecting balloon with manometer. G, gastric fistula (gastrostomy) in the fundic end of the stomach. B, balloon in stomach. E, esophagus ST, stomach D. duodenum CT, clamp and rubber tube. GP, glass pipette for introducing liquid substances directly into the stomach GF, glass funnel. RC. rubber cuff on end of pipette RO, rubber tube with open end in stomach S, silk thread holding rubber tubes together in the stomach.

FIG. 2 Monkey III, "Susie" Riding on the shoulder of an assistant. Note the friendliness and contentment.

normal movements of the stomach. However, a darkened room is preferable and, when an attendant knows how to handle a trained monkey, even a hungry one will lie quietly for three or four hours and will usually cuddle up and sleep for a considerable portion of the period.

Eight animals were used in this study of the normal movements of the empty stomach, three of which were trained to a point of proficiency, thus permitting the recording of the normal gastric activity. One of

FIG 3.—Monkey III, 'Susie.' Asleep in the arm of an assistant. Note the complete relaxation

these, "Susie," became a real pet and was given the freedom of the laboratory. There was nothing she enjoyed more than to ride on our shoulders, even clinging to maintain her balance while we were busily engaged in other duties. In the quietness of the laboratory she was perfectly at ease and apparently happy (Figs. 2, 3 and 4).

Studies were made on the movements of the empty stomach 18 to 24 hours after feeding and graphically recorded on a sixty minute drum.

FIG 4 — Monkey III, 'Susie" Showing characteristic position taken by animal during graphic registration of the movements of the empty stomach. Gastric fistula not shown in picture.

A water manometer was used with a pressure of from three to six centimeters and the animals were given a rest period of at least twenty-four hours following each experimental observation in order to keep them in normal physiological condition.

Acute Experiments

In the earlier phases of this work considerable fluctuations in gastric tone and reflex inhibition were observed. As a result, a series of acute

experiments were inaugurated in an attempt to determine the effects of nerve influence on the tonus and motor activity of the gastric mechanism. All these later experiments were performed under light ether anaesthesia in order to preserve the reflexes. The esophagus, vagi and carotids were exposed in the neck. A lateral incision through the wall of the esophagus admitted the stomach balloon for the recording of the gastric movements. The blood pressure was recorded simultaneously from the carotid or femoral artery and the splanchnic nerves were isolated for stimulation. In these acute experiments a fast of from forty to forty-eight hours was found to be more satisfactory.

THE CHARACTER OF THE MOVEMENTS OF THE EMPTY STOMACH OF THE MONKEY

The movements of the empty stomach in mammals were first studied by Boldyreff (1905, 1911) in dogs by means of the gastric fistula. Rubber balloons were introduced into the stomach and connected by air or water transmission to the recording manomater for graphic registration. According to this investigator the empty stomach of the dog exhibits alternating periods of rhythmical contractions and periods of complete quiescence during the first three or four days of fasting. The periods of activity vary in length from twenty to thirty minutes and the intervening periods of rest last from one and one-half to two and one-half hours. The period of activity begins with weak contractions and these increase gradually in strength until the period ends abruptly with the strongest contractions.

Cannon and Washburn (1912) have reported similar results from the empty stomach of man by introducing a balloon through the esophagus into the stomach. The observations were made six to twenty hours after meals and were directed towards establishing the relation between the contraction periods of the stomach and the sensation of hunger. They seem to agree with the previous investigator in the absolute quiescence of the stomach between the periods of the strong rhythmical contractions.

Our knowledge of gastric physiology has also been greatly advanced by the work of Carlson (1912) in an extensive series of studies carried out, not only on animals, but on a young man in normal health with a permanent gastric fistula—Fred Vlcek, the so-called second Alexis St. Martin. By the use of more delicate methods, Carlson has analyzed the various types of motor activities of the empty stomach during prolonged fasting, in which he has described three types of motor activity (1914).

Types of Hunger Contractions

1. Rhythmical contractions of about twenty-seconds duration and designated the "twenty-seconds rhythm."

2. Very vigorous contractions occurring periodically of about thirty-seconds duration and designated the "thirty-seconds rhythm."

3. Tonus changes of the stomach musculature.

While there is some indication of a feeble tonal rhythm during the rest period in one of the published tracings (Fig. 2) of Cannon and Washburn, the methods used by these investigators and more particularly by Boldyreff were not delicate enough to record the weaker contractions and the variations in tonus.

In dogs the movements of the empty stomach, as registered by means of a delicate balloon in the fundus, have been classified by Carlson (1913) into three distinct types, namely, Types I, II and III, each of which is thought to be dependent upon a particular degree of stomach tonus. *Type I* is exhibited when the stomach shows feeble tonus and the contractions have an average duration of about thirty seconds with the intervals between the contractions varying from half a minute to three or four minutes. *Type II* is exhibited when the stomach is in relatively strong tonus, the contractions following one another in rapid succession, that is, without any intervening pause. The duration of the contractions varies between twenty and thirty seconds. These contractions usually occur only in young and vigorous individuals in excellent physical condition. *Type III* is exhibited when the stomach constitutes virtually an incomplete tetanus characterized by periods of strong and relatively persistent tonus on which are superimposed a series of rapid contractions. The duration of these rapid contractions averages from twelve to fifteen seconds and they are thought to be analogous to the twenty-seconds rhythm in man.

The three types of contractions may be observed in the same dog on different days, or Type I may be exhibited for a few days and then be superseded by Type II, etc. In general, Type I predominates in some dogs and Types II and III in others, while some of the tracings exhibit transition stages. This is to be expected, since the types of hunger contractions seem to vary with the degree of gastric tonus, and this tonus may vary considerably during a single observation period. In man, however, the movements of the empty stomach are confined more especially to the twenty and thirty-seconds rhythms and, although similar in character,

they do not correspond in every detail with the three types of gastric hunger contractions exhibited in the dog's stomach.

The contractions of the empty stomach of the monkey, as registered by means of a delicate rubber balloon in the fundus, are practically identical with those of man. The stomach of this animal exhibits a definite periodicity, characteristic of the gastric hunger activity of higher animals, the contractions falling into groups, separated by intervals of relative quiescence. The duration of the groups or periods of hunger activity vary from one hour and forty minutes to two hours; the quiescent or rest periods, from ten to twenty minutes, thus making the monkey occupy a somewhat intermediate position between the five to six months' pup and the young adult dog. The rest periods appear to be short but, as previously stated, only young, vigorous animals were employed in these experiments in which the gastric activity is thought to be dependent upon the factor of age. This is to be expected, since Patterson (1914) showed conclusively in the case of dogs of different ages that the periods of quiescence are the longest in old dogs. These periods range from one and one-sixth to four and one-sixth hours, and rapidly decrease in length proportionately to age, being from three and four-tenths to two and one-half minutes in the baby pup of five or six weeks. Conversely the periods of contraction are the longest in the baby pup. These periods range from four and one-half to five and two-thirds hours and then rapidly decrease in length proportionately to age in the old dogs from two hours to thirty minutes, thus showing that the stomach's activity is in direct proportion to the age of the animal.

These results on the rhythmical contractions of the empty stomach in dogs are not in accord with those of Boldyreff (1905), since his account of this rhythm is incomplete and partly misleading. The length of both the contraction and the quiescent periods as observed by Boldyreff seems, on the whole, to be considerably less than that shown in the author's series of old dogs and they are also practically identical with those reported by Carlson (1913) on adult dogs. According to Boldyreff the contractions always come in groups of from twenty to thirty minutes duration, and during the one and one-half to two and one-half hours interval between these groups the stomach is completely quiescent. The contractions observed were probably those of a feeble Type I group but it is evident this investigator never obtained the Types II and III rhythm in his animals.

The difference in the results of Boldyreff and those of Carlson (1913) and Patterson (1914) is probably due to the condition of the animals,

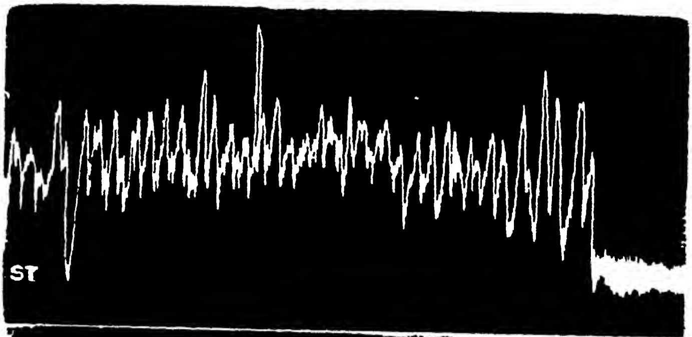
the methods of handling, and the method of registering the stomach contractions, for Boldyreff's dogs were forced by mechanical means to lie or stand in one position for six to twelve hours at a time. This forced position, as well as the classical silver cannula used in the gastric fistula, probably in part produced the brevity of the contraction periods, for all such influences tend to depress the gastric activity. Furthermore, all of these dogs, in addition to the gastric fistula in the fundus of the stomach, also possessed duodenal, pyloric, pancreatic or hepatic fistulæ. The animals, therefore, were subjected to much greater disturbances of digestion and metabolism than the animals under discussion in this paper, which were permitted to lie comfortably in the lap of an attendant and usually without restraint, a condition which is certainly more nearly normal. In addition, Boldyreff's published tracings do not show the respiratory intragastric pressures, nor do they indicate the slightest variations of the gastric tonus during the observation periods. It is, therefore, evident that his recording apparatus was not delicate enough to detect small variations in the intragastric pressure.

In man and dog the fundic end of the stomach, during normal digestion, exhibits a slow tonus rhythm which, during the emptying of the stomach and the onset of the hunger period, becomes more vigorous (Rogers and Hardt, 1915). Upon this slow rising tonus rhythm the peristaltic waves arise from points higher and higher toward the cardiac end of the stomach and sweep downward over the organ. In all observations on the monkey the empty stomach exhibits, on the whole, greater tonus and motor activity than the filled stomach. In this animal two types of rhythmical contractions have been observed which alternate with periods of relative quiescence. The individual contractions of the more powerful type have a duration of about thirty-seconds and are comparable to the "thirty-seconds rhythm" in man. The other pressure rhythm thought to be due to a tonus contraction of the fundus or peristalsis of the antrum has an individual duration of approximately twenty seconds and likewise is comparable to the "twenty-seconds rhythm" in man.

No feeble contraction periods have been observed in any of the monkeys studied, due, evidently, to the fact that all the animals were young and vigorous. Such contractions would more likely occur in old animals or those in a state of depression from illness or other disturbing factors. The contractions forming the periods of strong hunger activity usually begin as feeble tonus rhythms which gradually increase in

amplitude with a simultaneous shortening of the intervening intervals of rest and may or may not end in tetanus or prolonged tonus contractions, followed by a relatively abrupt relaxation and quiescence in which only a respiratory pressure rhythm is present (Fig. 5A). The periods of more powerful contractions are also initiated by weak contractions with rather long intervening pauses, which gradually become shorter as the amplitude of the individual contractions increase until the climax is reached in a number of very powerful and rapid contractions of the order of incomplete tetanus. The tetanus usually lasts from two to five minutes and the cessation of these periods of hunger activity is always abrupt (Fig. 5B). This prolonged period of incomplete tetanus at the

A



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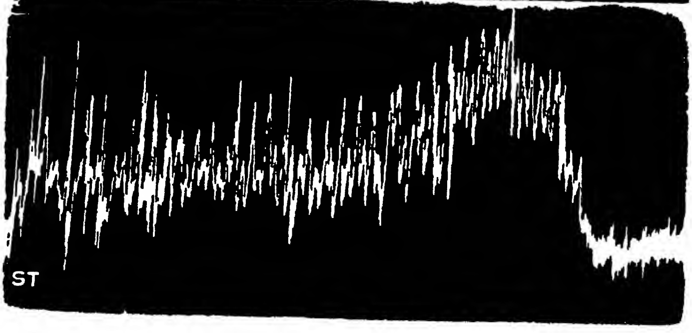

FIG. 5.—About one-half the original size. Monkey III, "Susie." Records of the contractions of the empty stomach of the normal young adult. A, final twenty minutes of a typical period of hunger contractions twenty-two hours after eating. B, final twenty minutes of a typical hunger period after a fast of twenty-seven and one-half hours. Note in tracing B the prolonged period of incomplete tetanus at the culmination of the hunger period, and the reappearance of a feeble 20-seconds rhythm immediately following the cessation of the period of strong hunger contractions. Note also the increase in the tonus and the hunger contractions of the empty stomach during prolonged fasting. Water manometer. St, Stomach contractions.

culmination of the hunger period with the reappearance of a feeble twenty-seconds rhythm immediately following the cessation of the period of strong hunger contractions is frequently seen in the monkey's stomach and corresponds to that observed by Carlson (1914) in man. It more often occurs in prolonged fasting or in cases where there is a considerable increase in tonus and the hunger contractions of the empty stomach.

These results seem to challenge the correctness of the statements of Boldyreff (1905) and of Cannon and Washburn (1912) that the stomach is completely at rest between the periods of the thirty-seconds rhythm. Mangold (1911) also claims that the completely empty muscular stomach of the buzzard is quiescent, but Rossi (1905) maintains that the activity of the stomach of chickens is more vigorous when empty than during digestion. In the monkey there is an increase in the gastric tonus and the hunger contractions and the intensity of this activity is also evidenced in the appearance of the incomplete hunger tetanus. The gastric hunger contractions in monkeys also go on in sleep with the same frequency and intensity as during the waking state, as has been determined by continuous gastric registration covering periods of from four to six hours in which the animals have slept during portions of these periods.

During the quiescent periods of the stomach the animals are more at ease and more likely to drop off to sleep than is the case during the strong periods of hunger activity. The strong contractions arouse and may even awaken the animals from sleep and they sometimes moan. As a result, they become restless, due to the discomfort of the hunger pangs, which are primarily produced by the contractions of the wall of the stomach.

THE INHIBITION OF THE MOVEMENTS OF THE EMPTY STOMACH OF THE MONKEY

Inhibition by Acid and Alkali

The tonus and hunger contractions of the empty stomach in man and dog are temporarily inhibited by mechanical and chemical stimulation of the nerve endings in the mucous membrane of the mouth, the esophagus and the gastric mucosa (Carlson, 1913). Brunemeier and Carlson (1915) have, however, produced similar inhibitory action on the dog's stomach from stimulation of the intestinal mucosa. The stomachs of many other animals also respond in an inhibitory manner, as is shown in rabbits, pigeons, frogs and molluscs (Rogers, 1915, 1916; Patterson,

1927, 1916, 1924). Gastric inhibition in the monkey is practically identical with that in man and the higher animals.

When water, 1 per cent sodium carbonate or 0.5 per cent hydrochloric acid, are introduced slowly and directly into the stomach through a pipette and small rubber tube passing through the gastrostomy opening, they invariably produce inhibition, the degree of intensity of the inhibition

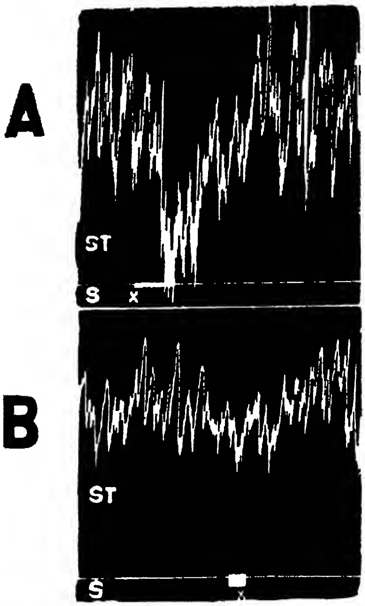

FIG. 6.—About one-half the original size. Monkey III, "Susie." Records from the empty stomach of the young adult. A, part of a period of strong hunger contractions twenty-two hours after eating. At x, 10 cc., water introduced directly into the stomach, producing a temporary inhibition with a lowering of the gastric tonus. B, hunger contractions after a fast of twenty-five hours. At x, the pad of the hind foot was tickled while the animal was asleep. Note diminution in amplitude of contractions. Water manometer. St, stomach contractions. S, signal.

being increased by the substances as listed in the order of their potency (Fig. 1). The duration of the inhibition depends upon the quantity and nature of the material introduced and varies in its degree with the stimulating power of the substance employed. Water, although the least effective of the three substances used, produces a marked fall in gastric tonus with a temporary inhibition of the hunger contractions of from two to three minutes duration (Fig. 6A). The water introduced into the stomach was at room temperature and apparently produced the inhibition through a stimulation of the nerve endings in the gastric mucosa, either by mechanical pressure or by osmosis. According to this view, the passage of the water out of the stomach into the intestine, or the addition of sufficient salts to prevent stimulation by hypotonicity would mark the cessation of the inhibition. The water (10cc.) was probably not cold enough or in sufficient quantity to stimulate the protopathic temperature nerve

endings in addition to those acted upon by pressure and osmosis, so that the results overbalance any error that might be accounted for by the cold water cooling the air in the balloon and thereby temporarily lowering the tension to an appreciable degree.

The introduction of 10 cc. of sodium carbonate, 1 per cent solution, directly into the monkey's stomach produces a more pronounced inhibitory effect than water. This inhibition is probably due to the alkalinity, rather than to the bulk of the solution, since Carlson (1913) has shown in the stomach of man that sodium carbonate in concentrations of 0.2 per cent or less appears to have the same influence on the hunger contractions as equal quantities of water. In greater concentrations (0.2 to 1.0 per cent) the degree of inhibition produced is on the whole directly proportional to the concentration and the quantity of the solution introduced into the stomach. For example, an introduction of 5 cc. of 1 per cent sodium carbonate into the monkey's stomach may or may not produce the temporary inhibition. Alkalinity produces the same effect on the stomach as acidity, only to a lesser degree, both acids and alkalies causing inhibition without any after effect of the nature of augmentation. Since sodium carbonate in a 0.2 per cent solution or less has no more effect on the hunger motility than equal quantities of water, it would seem to indicate that a slight alkalinity of the gastric mucosa was compatible with the hunger contractions of the empty stomach. This may explain the fact why entrance of bile or intestinal juice into the stomach produces little or no effect on the hunger activity unless the concentration becomes sufficiently high to effect the usual inhibition.

All acids, or liquids containing acids, including normal gastric juice, cause inhibition of the movements and the tonus of the empty stomach when introduced directly into the stomach cavity. In the monkey, the introduction of 5 to 10 cc. of 0.5 per cent hydrochloric acid directly into the stomach is more effective than the alkali, producing complete inhibition of the movements of the empty stomach. The duration of this period of acid inhibition varies from twenty to forty-five minutes or more and is probably determined by three factors, namely, (1) passing of the acid into the duodenum, (2) fixation and neutralization of the acid of the mucous gastric secretion, (3) neutralization by bile and intestinal juice, which at times pass into the stomach through the dilated pylorus. Normal gastric juice of full normal acidity (0.48 to 0.53 per cent) and other acid solutions inhibit the hunger contractions, but it does not follow that a neutral or alkaline reaction in the stomach cavity

is a prerequisite for these contractions, because, as pointed out by Carlson (1913), the contractions reappear again before all the acid has passed out of the stomach or has been completely neutralized. In other words, the hunger contractions are not inhibited by weak concentrations of acids in the stomach, nor is it necessary that the gastric mucosa show a neutral or alkaline reaction. In fact, it is now believed that the hydrochloric acid of the gastric juice constitutes the stimulus that leads to the inhibition when the concentration of the acid rises to too high a level of concentration. None of these substances have been introduced into the mouth or the intestine to determine their influence on the motor activity of the empty stomach of the monkey.

Mechanical stimulation (tickling) of the pads of the feet, posterior limbs, when the animal is asleep, causes a slight fall in the amplitude or strength of the hunger contractions (Fig. 6B). This result, however, establishes the possibility of a reflex action over the afferent fibers of the sciatic nerve which is capable of influencing the gastric activity.

Reflex Inhibition by Mechanical Stimuli

Reflex or psychic inhibition of the hunger contractions occurs whenever an animal is annoyed, angered or frightened or whenever cerebral processes of strong emotions of pleasure are involved, such as the entrance of a friend (animal keeper) into the room. In this connection the influence on the hunger contractions of the sight and smell of palatable foods was investigated. In Vlcek, when hungry, such psychic stimuli did not seem to affect his gastric hunger contractions, but in certain other human individuals positive reactions have been obtained. In dogs the sight and smell of food lead to temporary inhibition of the hunger contractions, and the inhibition is directly proportional to the degree of interest taken in the food. This is a true reflex or psychic inhibition, since it appears too quickly and is too temporary to be caused by a psychical secretion of gastric juice from the stomach mucosa (acid inhibition). Dogs usually react well to the sight and smell of food during the first few tests but later, when they learn that they are not to be given the food, they lose interest and pay little attention to the food shown them, with the result that the hunger contractions are no longer affected by such psychic stimuli. The particular inhibition here illustrated is of the order of "conditioned" reflexes and is similar to Pavlov's (1902) "psychic" secretion of gastric juice resulting from the seeing and smelling of palatable food. These reflexes require the presence of hunger and appetite as well as a certain fixation of the attention on the food.

Effect of Feeding Small Quantities of Food

The reaction of the monkey to the sight and smell of palatable food is in confirmation of the statements above, and, on the whole, appears to be more closely related to that of the stomach of man than to that of the dog (Fig. 7C). The effect of feeding very small quantities of food, such as one, two or three sunflower seeds at a time, does not produce an in-

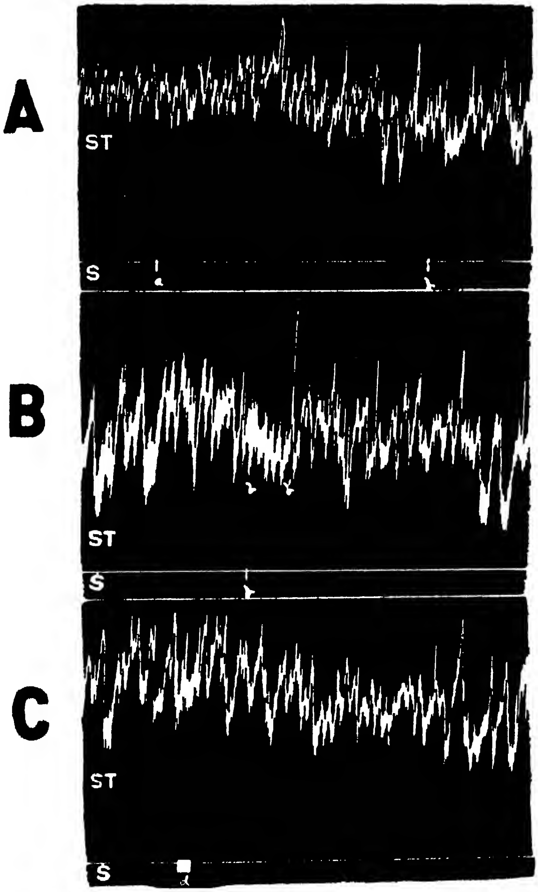

Fig. 7.—About one-half the original size. Monkey III, "Susie." Records from the empty stomach of the young adult after a fast of twenty-five hours, showing the effect of feeding small quantities of food. A, feeding. At *a*, one sunflower seed; at *b*, two seeds. Note the total absence of inhibition. B, feeding. At *b*, slice of banana. *b* to *b'*, animal chewing. Note the slight inhibition. C, effect of sight of food on hunger contractions. At *d*, showed animal a banana. Note the slight inhibition in the amplitude of contractions. Water manometer. St, stomach contractions. S, signal.

hibition of the gastric tonus or hunger contractions (Fig. 7A) but, when larger portions are fed—as for example, a slice of banana—a definite fall in the gastric tonus and a diminution in the amplitude of the hunger contractions occur along with the swallowing of saliva (Fig. 7B). These results on the monkey are in accord with those of Ivy and Vloed-

man (1929), who found that in young dogs fasted 48 hours, 10 to 20 grams of ground, lean sausage caused only a temporary inhibition, corresponding in time and duration to the receptive relaxation of the stomach secondary to deglutition, the hunger period going on to completion in from 10 to 15 minutes. As much as from 75 to 100 grams of the lean sausage were required to cause complete inhibition.

THE GASTRO-NEURO-MUSCULAR MECHANISM

The Nature of the Gastric Response

The earlier phases of this investigation on the normal movements of the empty stomach of the monkey indicated that various types of external stimuli, acting on the animal, might produce more or less definite effects on the response of the gastric hunger mechanism reflexly, and that these responses were always in the direction of an inhibition. It was such observations as these that led up to the inauguration of this series of acute experiments on the monkey in an attempt to analyze more in detail the nature of the gastro-neuro-muscular response. It has been shown in the dog and in man that there may be rather sudden and marked fluctuations in the gastric tonus and less frequently augmentations in the gastric motility, and such reactions have also been observed in the monkey's stomach. Goltz (1872) found that various types of stimulation, applied to different parts of the frog's skin, led to an increased hypertonus and motility of the stomach. He did not, however, consider these effects as types of reflex activity but presumed that the intense stimuli employed paralyzed more or less completely the medullary center from which, under normal conditions, the tonic inhibitory impulses for the esophagus and stomach arose. These observations were confirmed by Contejean (1892) and Steinach (1898). Rogers and Bercovitz (1921) have stated that in the turtle no method of increasing gastric tonus is available by stimulation of the vagus, their results being either negative or in the direction of a slight inhibition. Openchowski (1889), on stimulation of the kidney, uterus, urinary bladder and sciatic nerve, has reported a reflex dilatation of the cardia.

1. THE INFLUENCE OF STIMULATION OF THE SCIATIC ON THE TONUS AND MOTILITY OF THE GASTRIC MECHANISM

When both vagi and the splanchnic nerves are intact, stimulation of the central end of the sciatic nerve with a weak tetanizing current results in either an augmentation or an inhibition of the stomach with

the characteristic rise in blood pressure. The response appears to be primarily dependent upon the pre-existing state of tonus of the gastric mechanism itself and may involve both tonus and movement, these varying quite independently of each other. If the stomach is hypertonic

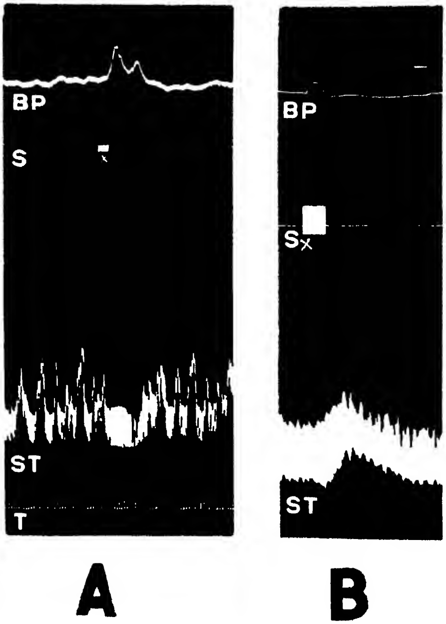

FIG. 8.—About one-half the original size. Monkey XII. Light ether anaesthesia. Vagi and splanchnic nerves intact. A, stomach hypertonic and active. At x, weak tetanizing current applied to central end of left sciatic, producing temporary inhibition of contractions and tonus. B, Monkey XXVIII, stomach hypotonic and quiescent. At x, moderate traction on left uncut sciatic, producing an augmentation in tonus. Note pre-existing state of gastric mechanism determines the type of muscular response. Water manometer. BP, blood pressure. S, signal. St, stomach contractions. T, time in 5 second intervals.

and exhibiting contractions, central stimulation of the above nerve will produce a temporary reflex inhibition of the gastric hunger contractions (Fig. 8A). On the contrary, if the stomach is hypotonic and quiescent, with the exception of the respiratory intragastric pressures, then such stimulation will lead to a decided increase in the gastric tonus (Fig. 8B).

All of these results are usually not obtained from the same animal for the state of tonus of the organ may remain more or less constant throughout the course of an entire experiment covering four to six hours, but once in a while, an animal will actually show during the course of an experiment a distinct fluctuation in gastric tonus. Figures 9A, B, C and D show an animal in which such a change in gastric tonus occurred and the actual time covered was about thirty-five minutes in the four tracings. In this experiment moderate traction was used on the central end of the sciatic. In figure 9A the stomach is quiescent and hypotonic. Stimulation by traction results in an increase in the gastric tonus along

with the typical rise in blood pressure. This effect was obtained several times by such stimulation previous to this curve and then without any warning or further stimulation the tonus of the stomach began to increase and, in order to prevent air from escaping through the manometer, it was necessary to open the clip on the instrument to reduce

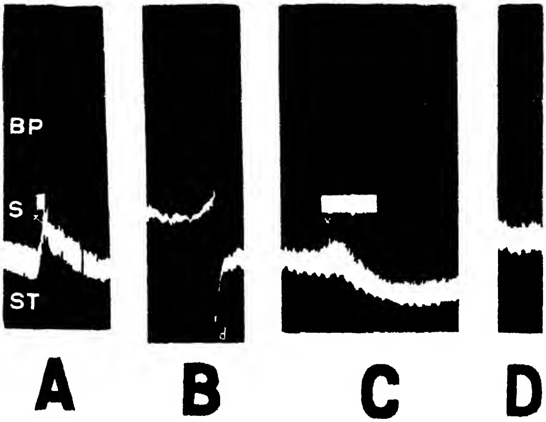

FIG. 9.—About one-half the original size. Monkey XXIII. Light ether anaesthesia. Vagi and splanchnic nerves intact. Records showing change in gastric tonus on a quiescent stomach and covering a period of about 35 minutes. A, stomach hypotonic. At x, moderate traction on left uncut sciatic, producing an augmentation in tonus. B, gradual increase in gastric tonus in absence of any artificial stimulus. At *d*, air pressure in balloon reduced to establish a new tonus level. C, stomach hypertonic. At x, same stimulus applied as in A but producing exactly the opposite effect on the gastric response. D, recovery to normal level of gastric tonus. Water manometer. BP, blood pressure. S, signal. St, stomach contractions.

the air pressure in the stomach balloon, which is indicated by the vertical line marked *d* in figure 9B. With the establishment of a new tonus level the stimulation was again repeated with the same effect on the blood pressure but with exactly the opposite effect on the gastric tonus. This means that the stomach had passed from the hypotonic to the hypertonic condition and again, on receiving the same stimulus through the nerve, responded with a fall in gastric tonus (Fig. 9C). This reaction was obtained throughout the remainder of the experiment, which was continued for about three hours. The last curve (Fig. 9D) shows the normal level of gastric tonus following recovery from the previous stimulation.

In regard to the effect of sciatic stimulation following section of both vagi in the neck, the author's results on the monkey, so far, are negative,

but further investigations are under way to check up on this point. However, Wertheimer (1892) found that sciatic stimulation caused inhibition of the stomach and that this reflex was decreased by section of the vagi, but not entirely abolished by subsequent section of both splanchnic nerves.

2. THE INFLUENCE OF STIMULATION OF THE VAGUS ON THE TONUS AND MOTILITY OF THE GASTRIC MECHANISM

Stimulation of the peripheral cut end of the vagus with a medium tetanizing current produces the characteristic fall in blood pressure accompanied by a powerful contraction of the stomach, which is then followed by a temporary inhibition of the gastric tonus (Fig. 10A).

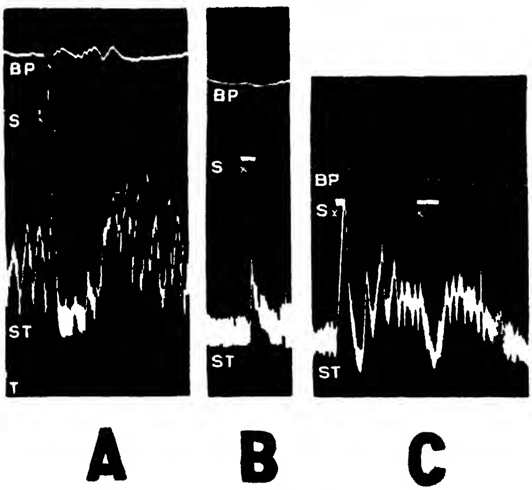

FIG. 10.—About one-half the original size. Monkey XII. Light ether anaesthesia. Vagi cut. A, stomach hypertonic and active. At x, weak tetanizing current applied to peripheral end of right vagus, producing a powerful gastric contraction followed by a fall in tonus. B, Monkey XVI, stomach hypotonic and quiescent. At x, same stimulus applied as in A but producing gastric spasm. C, Monkey XXIV, stomach quiescent and hypotonic. At x, same stimulus applied as in A and B, producing powerful gastric contraction and throwing stomach into period of activity. This is inhibited if the stimulus is again repeated at x′, but there is recovery and the period goes on to completion. Water manometer. BP, blood pressure. S, signal. St, stomach contractions. T, time in 5 second intervals.

The stomach is exhibiting good contractions and may be assumed to be in a medium state of hypertonus. In the next curve the stomach is hypotonic and the weak stimulus, when applied to the nerve, produces a slight fall in blood pressure accompanied by a spasm of the stomach and an increase in the gastric tonus (Fig. 10B). In the third tracing

weak peripheral vagal stimulation in the quiescent hypotonic stomach causes a powerful contraction with a fall in blood pressure. This gastric contraction after a slight fall in tonus is followed by a group of contractions on an elevated tonus level.

If the nerve stimulus is again repeated at x′, exactly the opposite effect now occurs in the stomach, namely, temporary inhibition of contractions with a marked fall in gastric tonus, and the contraction period apparently goes on to completion regardless of its interruption and finally returns to the original tonus level which it possessed previous to the stimulation (Fig. 10C). This is illustrative of how the gastric tonus through a given artificial stimulus may be increased with the development of stomach motility and then inhibited by a second and similar stimulation of the nerve.

This is in accordance with the work of Rogers and Bercovitz (1921), who found that stimulation of the vagus in dogs and turtles may produce either an excitatory effect on gastric motility, or an inhibitory influence on gastric tone and contractions. Langley (1898) and May (1904) have reported similar results on the rabbit, cat and monkey. More recently, McCrea, McSwiney and Stopford (1925) have reported that the primary effect on the stomach of stimulating the peripheral cut end of either vagus in the rabbit, cat and dog, is dependent on the existing condition of the peripheral mechanism ("tonus") and may be inhibitor or augmentor. The inhibitor or augmentor effect may involve both "tonus" and movement. The final effect of stimulation is to bring about the augmentation of existing movement or to initiate movement. The augmentor response is commonly obtained from the resting stomach, the preliminary inhibitor response, from the active digesting stomach two to three hours after a meal. The "tonus" and contraction may vary inversely or directly and the authors think it probable that the entogastric pressure, excitability and response to stimulation are governed by the interaction of these various factors which together constitute the peripheral mechanism and that they are interdependent to a greater or lesser degree. The mechanism resulting in these effects is peripherally situated, for they occur after bilateral vagotomy. Furthermore, the response of the stomach to vagus stimulation depends not upon the frequency or intensity of the stimulus, as suggested by Veach (1925), but upon the condition of the peripheral mechanism (McSwiney and Wadge, 1928). The isolated pyloric portion of the stomach also reacts in a similar way (McCrea and McSwiney, 1926).

Similar results are also obtained on the monkey when the uncut vagus nerve is stimulated by moderate traction (Figs. 11A, B and C). In fact, various gradations of tonus are represented in these respective curves with the corresponding effects on gastric motility and blood pressure. By repeated moderate traction on the uncut vagus in the

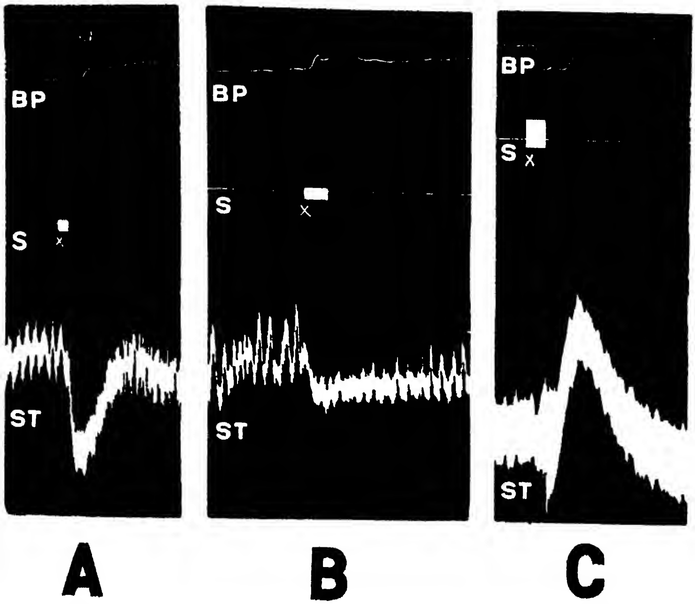

FIG. 11.—About one-half the original size. Monkey XV. Light ether anaesthesia. Vagi and splanchnic nerves intact. Records showing different gradations of gastric tonus with the effect of moderate traction on the uncut vagus. A, stomach strongly hypertonic and active. At x, stimulation of right uncut vagus, producing a marked fall in the gastric tonus. B, Monkey XVI, stomach moderately hypertonic and active. At x, stimulation of right uncut vagus, producing only a moderate fall in the gastric tonus. C, Monkey XXVIII, stomach markedly hypotonic and quiescent. At x, stimulation of left uncut vagus, producing a powerful spasm. Water manometer. BP, blood pressure. S, signal. St, stomach contractions.

stomach of certain animals when in a condition of hypertonus, it is not only possible markedly to reduce the gastric tonus but also to throw the gastric mechanism into a state of motility for short periods, as is indicated by application of stimulus at x′ (Fig. 12). These results offer additional evidence that the response of the gastro-neuro-muscular mechanism is related to the pre-existing state of tonus of the organ, as was suggested by Carlson, Boyd and Pearcy (1922) in their explanation for the reflex control of the cardia and lower esophagus, for they also

obtained both inhibitor and augmentor effects. More recently Carlson (1930) has shown that stimulation of the peripheral end of the hypogastric nerves exerts opposite effects on the ascending and transverse colon. If this portion of the colon is relatively atonic at the time, the

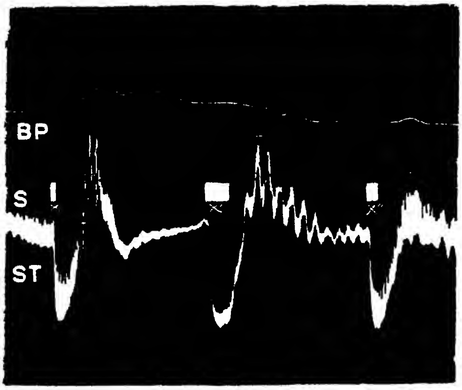

FIG. 12.—About one-half the original size. Monkey XXIII. Light ether anaesthesia. Vagi and splanchnic nerves intact. Stomach in a condition of hypertonus, showing the effect of repeated stimulation by moderate traction on the uncut right vagus at points x, x′, x″, respectively. Note the changes in gastric tonus and motility. Water manometer BP, blood pressure. S, signal. St, stomach contractions.

stimulation induces a powerful contraction of both the circular and the longitudinal musculature. On the contrary, if this portion of the intestine is in a fair degree of tonus or rhythmic contractions at the time of the stimulation, the tonus and motility are inhibited. Does this mean that we are dealing with both inhibitory and motor fibers in the hypogastric, or are these opposite effects produced by one kind of afferents, the specific effect depending on the tonus or motor state of the intestine at the moment of stimulation?

Experimental stimulation of the central end of the cut vagus with the opposite nerve intact probably produces effects on the gastric response similar to those caused by sciatic and peripheral vagus stimulations and therefore more or less dependent on the pre-existing state of tonus of the gastric mechanism. In support of this, however, Morat (1893) has obtained inhibition of the stomach on stimulation of the central end of one vagus, provided the other vagus remained intact. After section of both vagi, I have been unable to elicit this reflex but the work is not fully completed as yet on this particular phase of the question. Laughton (1929) has recently shown that faradic stimulation of the cephalic half of the dorsal vagus nuclei of the cat causes contractions in the stomach, although, if the organ is hypertonic at the time of stimulation, inhibition of tone results. The cephalic half of the left dorsal vagus nucleus gives a more marked effect on the stomach than stimulation of

the corresponding part of the right dorsal vagus nucleus, which is in accord with the findings of McCrea, McSwiney and Stopford (1925) that the left vagus gives a greater response than that of the right nerve.

3. THE INFLUENCE OF STIMULATION OF THE SPLANCHNICS ON THE TONUS AND MOTILITY OF THE GASTRIC MECHANISM

The splanchnic nerves are almost universally stated to be the inhibitor nerves of the stomach, but at times various investigators have noted augmentor effects. These nerves were isolated through a skin incision extending from the lateral edge of the deep muscles of the back medially and ventralward for about two inches. By this method the nerves were isolated outside of the peritoneal membrane after passing through the crura of the diaphragm, so that entrance into the abdominal cavity was not required for the exposure of the nerves for stimulation, a factor which is of great physiological importance in this type of experimentation. Van Braam Houckgeest (1873), Courtade and Guyon (1899) and Klee (1913) working on rabbits, cats and dogs have obtained inhibitory effects on the stomach from stimulation of the splanchnic nerves. Oser (1892), in dogs, obtained a weak contraction followed by a relaxation. Battelli (1896), in rabbits, cats, dogs and rats, obtained mostly inhibitory effects but a few of the augmentor type were observed. Morat (1893), in rabbits and dogs, and Doyon (1894) and Nolf (1925), in birds, obtained both inhibition and augmentation. Elliot (1905), in cats and rabbits, observed an inhibition of the cardia and a contracton of the pyloric sphincter. Carlson, Boyd and Pearcy (1922) observed both motor and inhibitor effects on the cardia and lower end of the esophagus.

In the monkey, stimulation of the peripheral cut end of the splanchnic nerve with a strong tetanizing current produces the typical rise in blood pressure accompanied, in some cases, by a decided fall in the gastric tonus, a condition probably created by the hypertonic state of the stomach (Fig. 13A). In the second curve, recorded from the same animal 35 minutes later, in which a similar stimulus was employed there is still the usual rise in blood pressure but here again we have just the opposite effect on the gastric tonus (Fig. 13B). This rise in tonus is probably due to the hypotonic state of the gastric mechanism. However, these reactions from splanchnic stimulation are not as marked as the results usually obtained from stimulation of other nerves already described in the monkey. They are, nevertheless, in general accord with the published results of McCrea and McSwiney (1928) on peripheral splanchnic stimulation in the cat and dog, with the exception that their

contractions are very much stronger than any which I was able to obtain. Stimulation of the central end of the splanchnic seems to exert some influence on the stomach at times, especially in the direction of a reflex

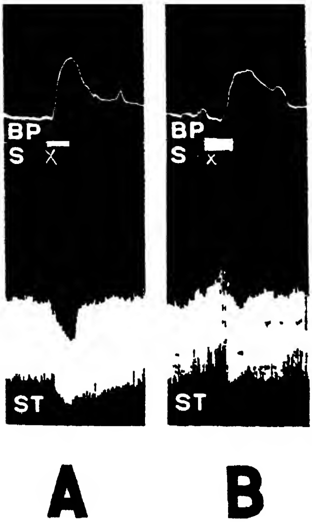

FIG. 13.—About one-half the original size. Monkey XXIV. Light ether anaesthesia. Records of effect of splanchnic stimulation on the gastric response. A, stomach hypertonic and quiescent. At x, strong tetanizing current applied to peripheral end of left splanchnic, producing a fall in gastric tonus with the characteristic rise in blood pressure. B, same animal 35 minutes later, stomach hypotonic and quiescent. At x, same stimulus applied as in A but producing exactly the opposite effect on the gastric tonus with the same blood pressure reaction as in A. Water manometer. BP, blood pressure. S, signal. St, stomach.

inhibition of tonus, but this is another phase of the work, which will require special attention for verification.

4. THE OCULOGASTRIC REFLEX FROM COMPRESSION OF THE EYEBALL

Compression of the eyeball may exert an influence on the gastric response and is probably dependent, as stated in other parts of this paper, on the pre-existing state of tonus of the peripheral gastric mechanism at the moment of the application of the stimulus. It was not possible to elicit this reflex from all animals studied but several on which it was tried gave favorable reactions. Moderate compression of the eyeball results in a fall in blood pressure and a fall in the gastric tonus, if the stomach is hypertonic (Fig. 14A). On the contrary, if the stomach is hypotonic, similar compression of the eyeball may result in a slight increase in gastric tonus along with the usual fall in blood pressure (Fig. 14B). However, the reflex increase in gastric tonus is much more difficult to obtain than the reflex inhibition of tonus, but it probably exists. These results are confirmatory of those of Danielopolu and Carniol (1924) in so far that compression of the eyeballs inhibits

the movements of the stomach. It is probable that all afferent sensory nerves of the body may exert a reflex influence on the gastro-neuromuscular mechanism.

DISCUSSION

The gastric reflexes described in the preceding sections are complex reactions depending not only on the condition of the central nervous system, but also on the pre-existing state of the gastric mechanism. It must not be inferred that all of these reflexes can be demonstrated in a single animal, even when extreme care is taken with the anaesthesia

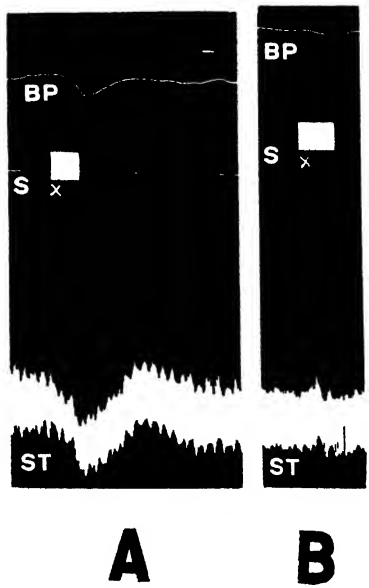

FIG. 14.—About one half the original size. Monkey XXVIII. Light ether anaesthesia. Vagi and splanchnic nerves intact. Gastric records on the compression of the eyeball—"oculogastric reflex." A, stomach hypertonic and quiescent. At x, moderate compression of the right eyeball, producing an inhibition of the gastric tonus and the blood pressure. B, same animal 20 minutes later, stomach hypotonic and quiescent. At x, moderate compression of the left eyeball, producing a slight increase in the gastric tonus and a similar blood pressure reaction as in A. Water manometer. BP, blood pressure. S, signal. St, stomach.

and the trauma of necessary dissections. The reflexes in some specimens were more readily elicited than in others, even under experimental conditions as nearly identical as possible. There is no real explanation to offer for these variations unless they are due to the unknown factor of central and peripheral "shock." In some of the animals a condition of "shock" surely existed, which varied from forty-five minutes to one and one-half hours during which the breathing might be shallow and the blood pressure very low. However, most of these animals made a good recovery and it was not until then that the actual experimentation was started.

The motor control of the stomach involves local automatism and reflexes via the Auerbach's plexus, long reflexes via the vagi efferents, and long reflexes via the splanchnic efferents. The long reflex mechanisms can be thrown into activity by the stimulation of such nerves as the sciatic, vagus and possibly the splanchnic, and it is also probable that stimulation of all sensory nerves throughout the body exerts an influence on the stomach via these mechanisms. Furthermore, the gastric response in these reflexes may be either relaxation or contraction, depending in large part on the pre-existing state of tonus of the stomach at the time of stimulation. If the stomach is in feeble tonus, the contraction reflex prevails; if it is in strong tonus, the inhibition reflex usually predominates. The inhibitor or augmentor effect may involve both "tonus" and movement.

McCrea and Macdonald (1928) have shown on cats and dogs that the effect produced by the intravenous administration of sympathomimetic (epinephrine, ephedrine, ergotamine) and para-sympathomimetic (pilocarpine, physostigmine, acetyl-choline) drugs, like stimulation of the splanchnic or vagus nerves, vary with the tone of the viscus, but do not closely duplicate the effects of faradic stimulation. More recently Thomas (1929) has demonstrated that the primary action of epinephrine on the pyloric sphincter of the dog, cat and rabbit in situ may cause either an increase or decrease of the tonus, the former when the muscle is relaxed and the latter when it is contracted. This also brings up the interesting question of variations in drug action on the stomach, which, on the basis of this investigation, has its explanation in the vexed question of "tonus." This merely denotes the state of the peripheral mechanism but it tells us nothing of its etiology. It is generally assumed that epinephrine acts on the myoneural junctions or what may be termed the peripheral neuro-muscular zone. The fibers of this connecting link between the nerve proper and the muscle are very small and must involve the question of excitability and conductivity, which may be altered by changes in isotonicity, nutrition, metabolism, hydrogen ion concentration, etc., favorable or unfavorable for the passage of nerve impulses, upon which it would be assumed that the production and maintenance of gastric tonus is dependent. Upon such a hypothesis, these facts would afford a solution of the question of the reflex coordination existent in the normal physiological state of the stomach and subject to the alterations in the chemical constitution of the tissues comprising the peripheral neuro-muscular zone.

CONCLUSION

1. The motility and tonus of the empty stomach of the monkey is practically identical with that of the empty stomach of man.

2. Substances introduced directly into the stomach (water, 1 per cent sodium carbonate and 0.5 per cent hydrochloric acid) produce gastric inhibition in proportion to the degree of their potency.

3. Very small amounts of food given to animals exhibit no inhibitory influence on the movements of the empty stomach; in larger quantities definite inhibitory effects result.

4. The sight of food, when in sufficient amounts, may also lead to an inhibition (psychic inhibition) of the motor activity and tonus of the stomach.

5. The same mechanism is probably involved in the inhibition of the movements of the empty stomach that is concerned in the inhibition of the movements of digestion.

6. Stimuli when applied to certain sensory surfaces of the body of the animal, such as the pad of the foot, may produce decided inhibitory effects.

7. Stimulation of the central portion of the sciatic results in either an augmentation or an inhibition of the stomach, the reaction appearing to be primarily dependent upon the pre-existing state of tonus of the gastric mechanism. If the stomach is hypertonic, reflex inhibition will follow central stimulation of this nerve; if hypotonic, a contraction may occur or there may be a definite increase in the tonus.

8. Stimulation of the peripheral end of either vagus produces a somewhat similar inhibitory or augmentory action, depending upon the degree of gastric tonus.

9. Peripheral splanchnic stimulation also exerts a similar but smaller response.

10. There is evidence that stimulation of the central portions of the vagus and splanchnic nerves produces, under certain conditions at least, a reflex inhibition of gastric tonus.

11. Compression of the eyeball leads in some animals to the production of an oculogastric reflex and the tonus change is dependent upon the state of tonicity of the stomach.

12. It is probable that stimulation of all sensory nerves in the body exerts an influence on the stomach via the long reflex mechanisms of the vagus and splanchnic efferents.

13. A proper analysis of this factor of gastric tonus would be a means of determining when the therapeutic use of epinepherine was indicated or contraindicated, involving conditions in which the stomach might be pathologically concerned.

14. The gastric response is dependent upon the pre-existing state of tonus of the gastro-neuro-muscular mechanism which may involve to a considerable extent the myoneural junction. Tonus and movement are both involved and these may vary quite independently of each other.

BIBLIOGRAPHY

Battelli, F.

1896. Action de diverses substances sur les mouvements de l'estomac, et innervation de cet organe. Compt. rend. Acad. d. sci., Paris, CXXII, pp. 1568-1570.

Beaumont, W.

1833. Experiments and observations on the gastric juice and the physiology of digestion. Printed by F. P. Allen, Plattsburgh, N. Y. pp. 1-280, 3 figs.

Boldyreff, W.

1905. Le Travail périodique de l'appareil digestif en dehors de la digestion. Arch. d. Sci. Biol., XI, pp. 1-5.

1911. Einige neue Seiten der Tätigkeit des Pankreas. Ergebn. d. Physiol., XI, pp. 121-217, 7 figs.

Brunemeier, E. H., and Carlson, A. J.

1915. Contributions to the physiology of the stomach. — XIX. Reflexes from the intestinal mucosa to the stomach. Am. Jour. Physiol., XXXVI. pp. 191-195, 2 figs.

Cannon, W. B., and Washburn, A. L.

1912. An explanation of hunger. Am. Jour. Physiol., XXIX, pp. 441-454, 3 figs.

Carlson, A. J.

1912. Contributions to the physiology of the stomach.—I. The character of the movements of the empty stomach in man. Am. Jour. Physiol., XXXI, pp. 151-168, 8 figs.

1913. Contributions to the physiology of the stomach.—III. The contractions of the empty stomach inhibited reflexly from the mouth. Am. Jour. Physiol., XXXI, pp. 212-222, 6 figs.

1913. Contributions to the physiology of the stomach.—V. The influence of stimulation of the gastric mucosa on the contractions of the empty stomach (hunger contractions) in man. Am. Jour. Physiol., XXXII, pp. 245-263, 5 figs.

1913. Contributions to the physiology of the stomach.—VI. A study of the mechanisms of the hunger contractions of the empty stomach by experiments on dogs. Am. Jour. Physiol., XXXII, pp. 369-388, 6 figs.

1913. Contributions to the physiology of the stomach.—VII. The inhibitory reflexes from the gastric mucosa. Am. Jour. Physiol., XXXII, pp. 389-397, 4 figs.

1914. Contributions to the physiology of the stomach.—VIII. The hunger contractions of the empty stomach during prolonged starvation (man, dog). Am. Jour. Physiol., XXXIII, pp. 95-118, 5 figs.

1916. The control of hunger in health and disease. The University of Chicago Press, Chicago, pp. 1-319, 38 figs.

1930. Extrinsic nervous control of the large bowel. Jour. Amer. Med. Assoc., XCIV, pp. 78-79.

Carlson, A. J., Boyd, T. E., and Pearcy, J. F.

1922. Studies on the visceral sensory nervous system.—XIV. The reflex control of the cardia and lower esophagus in mammals. Arch. Int. Med., XXX, pp. 409-433, 15 figs.

Contejean, C.

1892. Action des nerfs pneumogastrique et grand sympathique sur l'estomac chez les batraciens. Arch. de physiol. norm. et path. Paris, IV, 5. s., pp. 640-650.

Courtade, D., and Guyon, J. F.

1899. Contribution à l'étude de l'innervation motrice de l'estomac. Journ. de physiol. et de path. gén., Paris, I, pp. 38-46.

Danielopolu, D., and Carniol, A.

1924. Oculogastric reflex. Arch. des Maladies de l'App. Digestif, Paris, XIV, pp. 110-123.

Doyon, M.

1894. Recherches expérimentales sur l'innervation gastrique des oiseaux. Arch. de physiol. norm. et path., Paris, VI, 5. s., pp. 887-898.

Elliott, T. R.

1905. The action of adrenalin. Journ. Physiol., XXXII, pp. 401-467, 12 figs.

Goltz, F.

1872. Studien über die Bewegungen der Speiseröhre und des Magens des Frosches. Pflüger's Arch. f. d. gesammt. Physiol., VI, pp. 616-642.

Ivy, A. C.

1929. By personal communication.

Klee, P.

1913. Der Einfluss der Splanchnicusreizung auf den Ablauf der Verdauungsbewegungen. Pflüger's Arch. f. d. gesammt. Physiol., CLIV, pp. 552-570, 9 figs.

Langley, J. N.

1898. On inhibitory fibers in the vagus for the end of the œsophagus and the stomach. Journ. Physiol., XXIII, pp. 407-414.

Laughton, N. B.

1929. The effects on the stomach of stimulation of the dorsal vagus nuclei. Am. Jour. Physiol., LXXXIX, pp. 18-23, 7 figs.

May, W. P.
1902. On the movements and innervation of the stomach. Brit. Med. Jour., II, 779-781.
1904. The innervation of the sphincters and musculature of the stomach. Journ. Physiol., XXXI, pp. 260-271, 6 figs.

Mangold, E.
1911. Die funktionellen Schwankungen der Motorischen Tätigkeit des Raubvogelmagens. Pflüger's Arch. f. d. gesammt. Physiol., CXXXIX, pp. 10-32, 21 figs.

McCrea, E. D., McSwiney, B. A. and Stopford, J. S. B.
1925. The effect on the stomach of stimulation of the peripheral end of the vagus nerve. Quart. Jour. Exp. Physiol., XV, pp. 201-233, 20 figs.

McCrea, E. D., and McSwiney, B. A.
1926. The effect of stimulation of the vagi on the pyloric region of the stomach. Journ. Physiol., LXI., pp. 28-34, 5 figs.
1928. The effect on the stomach of stimulation of the peripheral end of the splanchnic nerve. Quart. Jour. Exp. Physiol., XVIII, pp. 301-313, 6 figs.

McCrea, E. D. and Macdonald, A. D.
1928. The action of drugs upon the movements of the stomach. Quart. Jour. Exp. Physiol., XIX, pp. 161-170, 6 figs.

McSwiney, B. A., and Wadge, W. J.
1928. Effects of variations in intensity and frequency on the contractions of the stomach obtained by stimulation of the vagus nerve. Journ. Physiol., LXV, pp. 350-356, 9 figs.

Morat, J. P.
1893. Sur quelques particularités de l'innervation motrice de l'estomac et de l'intestin. Arch. de physiol. norm. et path. Paris, V, 5. s., pp. 142-153.

Nolf, P.
1925. L'innervation motrice du tube digestif de l'oiseau. Arch. intern. de physiol., XXV, pp. 291-341.

Openchowski, T. von
1889. III. Ueber die gesammte Innervation des Magens. Deutsch. med. Wochenschr., XV, pp. 717-719, 1 fig.
1889. Ueber die nervösen Vorrichtungen des Magens. Zentralbl. f. Physiol., Leipz. u. Wien, III, pp. 1-10.

Oser, L.
1892. Experimentelle Beiträge zur Innervation des Magens. Zeitschr. f. klin. Med., Berlin, XX, pp. 285-297.

Patterson, T. L.
1914. Contributions to the physiology of the stomach.—XIII. The variations in the hunger contractions of the empty stomach with age. Am. Jour. Physiol., XXXIII, pp. 423-429, 3 figs.

1915. Contributions to the physiology of the stomach.—XXIII. The cause of the variations in the gastric hunger contractions with age. Am. Jour. Physiol., XXXVII, pp. 316-329, 4 figs.

1916. Contributions to the physiology of the stomach.—XXXVI. The physiology of the gastric hunger contractions in the Amphibia and the Reptilia. Comparative studies I. Am. Jour. Physiol., XLII, pp. 56-88, 11 figs.

1924. A study of the movements of the empty stomach in the Mollusca. Proc. Iowa Acad. Sci., XXXI, pp. 445-449, 4 figs.

1927. Gastric movements in the pigeon with economy of animal material. Comparative studies V. Jour. Lab. Clin. Med., XII, pp. 1003-1008, 6 figs.

PAVLOV, J. P.

1902. The work of the digestive glands. Charles Griffin & Company, Limited, London. Pp. 1-196, 19 figs.

ROGERS, F. T.

1915. Contributions to the physiology of the stomach.—XX. The contractions of the rabbit's stomach during hunger. Am. Jour. Physiol., XXXVI, pp. 183-190, 6 figs.

1916. Contributions to the physiology of the stomach.—XXXIX. The hunger mechanism of the pigeon and its relation to the central nervous system. Am. Jour. Physiol., XLI, pp. 555-570, 6 figs.

ROGERS, F. T., and BERCOVITZ, Z.

1921. A note on the role of the intrinsic plexuses in determining the effects on gastric motility of vagus stimulation. Am. Jour. Physiol., LVI, pp. 257-263, 4 figs.

ROGERS, F. T., and HARDT, L. L. J.

1915. Contributions to the physiology of the stomach.—XXVI. The relation between the digestion contractions of the filled, and the hunger contractions of the "empty" stomach. Am. Jour. Physiol., XXXVIII, pp. 274-284, 8 figs.

ROSSI, G.

1905. Sulla meccanica dell'apparato digerente del pollo. Arch. d. Fisiol., II, pp. 375-383.

STEINACH, E.

1898. Ueber die viscero-motorischen Functionen der Hinterwurzeln und über die tonische Hemmungswirkung der Medulla oblongata auf den Darm des Frosches. Pflüger's Arch. f. d. gesammt. Physiol., LXXI, pp. 523-554.

THOMAS, J. E.

1929. A further study of the nervous control of the pyloric sphincter. Am. Jour. Physiol., LXXXVIII, pp. 498-518, 6 figs.

VAN BRAAM-HOUCKGEEST.

1874. Zweite Mittheilung über Magen—und Darmperistaltik. Pflüger's Arch. f. d. gesammt. Physiol., VIII, pp. 163-171.

VEACH, H. O.

1925. Studies on the innervation of smooth muscle.—I. Vagus effects on the lower end of the esophagus, cardia and stomach of the cat, and the stomach and lung of the turtle in relation to Wedensky inhibition. Am. Jour. Physiol., LXXI, pp. 229-264, 19 figs.

WERTHEIMER, E.

1892. Inhibition réflexe du tonus et des mouvements de l'estomac. Arch. de physiol. norm. et path., Paris, IV, 5. s., pp. 379-385.

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WIND GAPS AND WATER GAPS OF THE NORTHERN APPALACHIANS, THEIR CHARACTERISTICS AND SIGNIFICANCE

BY

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CONTENTS

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INTRODUCTION

Arthur Keith (*4*) and Joseph Barrell (*1*) have emphasized the value of wind gaps as indicators of fluvial base levels.* Barrell (*1*), pp. 338-348, uses wind gap elevation, the form of the wind and water gaps, and the form of the valleys, as evidence in support of peneplanation or erosion cycles. He believes that wind gap elevations acquire a significance from their general accordance with a base level otherwise determined. The forms of the wind and water gaps, he points out, may give valuable evidence as to the nature of at least one and perhaps several erosion cycles. Barrell emphasizes the importance of facets in the profiles of the gaps, which he thinks are indicative of stillstands of the land during which peneplanation occurred.

More recently Eleanor Bliss Knopf (*5*) has attempted to correlate residual erosion surfaces in the eastern Appalachian highlands. She follows the ideas of Barrell and in like manner uses wind gap elevations, the form of the wind and water gaps, and the form of the valleys, as evidence of former peneplane levels developed during halts in the general uplift of the land.

The writer constructed profiles along the crests of the ridges in eastern Pennsylvania, and during the summer of 1928 made a careful field study of the wind and water gaps in this region. As a result of this investigation, he reached the conclusion that wind gap elevations have no value as indicators of fluvial base levels. The facets observed in some of the gaps appear to be due to structural or other conditions unrelated to former peneplane levels.

ACKNOWLEDGMENTS

The research upon which this paper is based involved both field and laboratory work carried on in connection with work for the Doctor's degree at Columbia University. The investigation was proposed by Professor Douglas Johnson, and formed part of a larger study of Appalachian erosion levels being conducted at Columbia with aid from the University's research funds. As a matter of personal acknowledgment, it goes without saying that the writer is profoundly indebted to Professor Johnson, under whose supervision the work was carried out.

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* Throughout the present paper the numbers in italics enclosed by parenthesis refer to works similar designated in the Bibliography.

Columbia University for many kindnesses, helpful advice and inspiration, and to Miss Amy Hepburn, librarian, for her assistance in securing maps and publications.

WHAT PENEPLANE IS REPRESENTED ON THE CRESTS OF THE APPALACHIAN RIDGES?

The earliest peneplane that can be traced in eastern Pennsylvania is represented by the accordant ridge tops. If it were possible to fill the deep valleys level with the hilltops of the region, we could restore the original plain, which would extend over both weak and hard rocks. Its elevation on Blue Mountain varies from a point as low as 1160 feet A. T. near the Susquehanna River, to a point as high as 1809 feet A. T. in the Port Jervis quadrangle. It is probable that the peneplane everywhere sloped toward the streams and toward the sea. The most resistant rock areas formed low monadnocks on a nearly featureless plain, worn down to a base level not far above the sea.

The writer constructed longitudinal profiles along all the ridges north of the Great Valley and twenty-six cross profiles across the Triassic Lowland, the Highlands in New Jersey, the Great Valley and the ridge and valley area in eastern Pennsylvania. They were drawn at intervals averaging six inches in width and along selected areas best representing the features intended to be emphasized. With this material at hand it is possible to form an opinion as to the probable existence of two peneplanes which, it is maintained, constitute the upland surface.

Barrell (*1*) and Bascom (*2*) have advocated the hypothesis of two peneplanes, one developed at the elevation represented by the even crest of Kittatinny Mountain, about 1600 feet A. T., and the other by the flat top of Schooley Mountain, and having an elevation on Blue Mountain of about 1350 feet A. T. Probably the reasons for such a stand are the difference in altitude of the two mountains and the somewhat greater warping required to make such a variation. Barrell (*1*, pp. 338-348) uses wind gap elevations, wind gap form and the forms of the valleys in eastern Pennsylvania as evidence in support of peneplanation.

In another part of this paper the present writer gives his reasons for believing that the conclusions set forth by Barrell cannot be accepted as valid. In the ridge and valley region of eastern Pennsylvania there appears to be little, if any, evidence of a peneplane at an elevation of 1300 to 1400 feet A. T., as postulated by Barrell (*1*, p. 339). He states that wind gap elevations acquire a significance from their general accordance with a base level otherwise determined. However, wind gaps

are no more frequent at the elevations from 1300 to 1400 feet A. T. than at any other altitude. The results obtained by the present writer indicate that wind gap elevations and peneplanation have no relation. Wind gaps occur at all elevations and are so irregularly distributed that it is certain that no accordance in their levels, due to peneplanation, occurs anywhere in the region.

Barrell appeals to the form of the wind gaps as further proof of fluvial base levels. From the examination of all the wind and water gaps in the field and on the topographic maps of eastern Pennsylvania, the present writer has been unable to find any facets which cannot be more reasonably ascribed to factors other than stillstands of the land during which peneplanation occurred. Careful examination of the Pen Argyl Wind Gap and the Delaware and Lehigh water gaps in the field failed to reveal facets or changes of slope which cannot be readily explained as due to the unequal erosion of rock formations of moderate inclination, but of variable resistance. The facets or changes in slope are local and are found at all elevations, and no accordance in their elevation occurs in the gaps of the region. Facets often appear on one side of the gap only, and at a distance their sides seem to be quite smooth, due to the fact that the changes in slope are local and only minor features. This is explained by irregularity in the resistance of the beds constituting the Shawangunk conglomerate.

The presence of broad valleys on the upper surface at about 1300 to 1400 feet A. T., below which the streams have entrenched themselves, would accord with the view that on a peneplane the stream valleys should be at the lower altitudes. The lowest points on any erosion surface are the stream valleys, even on a thoroughly peneplaned surface such as the upper level. The upper, flatter slopes indicate a period of erosion sufficiently long to produce a peneplane, followed by an uplift so recent that the rivers have had time only to carve young valleys in the old valley floors. The young valleys are the V-shaped wind and water gaps of the region.

The elevation of the highest points on the upper level occurs on the old divides (Fig. 1), which are well preserved on the sandstone and quartzite ridges of eastern Pennsylvania. A study of the longitudinal profiles drawn along the ridges show everywhere an undulating surface gently sloping toward the broad, nearly flat valleys, below which the streams have cut their gaps. Many of these old valleys on Blue Mountain are as low or lower than 1300 feet A. T., whereas the highest divides reach an altitude of about 1600 feet A. T. or more, giving a difference of

300 ft., which is not too great to expect even on a surface worn down to a low, featureless peneplane. In view of the strong evidence against the hypothesis, it seems very unlikely that a peneplane lower than the Kittatinny occurred at the elevation of about 1350 feet A. T. and which Barrell correlates with that on the top of Schooley Mountain. The evidence is decidedly in favor of but one upper level, the elevation of which varies somewhat, due to an undulating surface such as might be expected even when thoroughly peneplaned. One would expect to find, preserved on the hard rock ridges, the higher elevations which constituted the divides between the streams on the upper level. The streams which occupy the gaps at present and those which occurred in the wind gaps were originally superposed across the ridges, and once found place in the broad, shallow valleys on the upper level. Hence the presence of fossil divides, which have in most cases no relation to those of the present, is to be expected. After the uplift and warping of the upper level, the divides on the hard rock ridges would be preserved, while new ones would be developed by the headward erosion of the subsequent streams on the softer rock formations.

Accompanying this discussion is a profile (Fig. 1) drawn along the crest of Blue Mountain from the western limit of the New Bloomfield, Pa., quadrangle to the eastern limit of the Port Jervis, N. Y., quadrangle. A careful study of the profile reveals that for long distances on either side of the water gaps and major wind gaps, the ridge crests representing the upper (Schooley or Kittatinny) peneplane descend faintly toward the major stream courses. This is true not only for Blue Mountain but for the other ridges to the northwest of which profiles have been constructed. The approximate position of the fossil divides on the ridge crest is indicated on the profile (Fig. 1). Some of these divides are broad and appear to be flat-topped or gently rounded. This is what one would expect on a land surface worn down to a peneplane. The broad, gently rounded divides cannot be remnants of an older, higher peneplane, but are more reasonably interpreted as the divides on the Schooley (Kittatinny) peneplane preserved on the hard rock ridges.

If the two surfaces represented by the nearly level top of Kittatinny and Schooley Mountains constitute, as claimed by Barrell and Bascom, two distinct cycles of erosion, we should expect to find in eastern Pennsylvania evidence of a lower surface, thoroughly peneplaned and easily correlated with its equivalent on Schooley Mountain. The writer has been unable to find proof of the existence of more than one peneplane. It is highly improbable that on the same rock there would still be pre-

served relatively flat or gently undulating remnants of an older, higher peneplane with a later peneplane worn down to extreme old age at a lower level. It seems almost inevitable that higher areas, if they exist, would be thoroughly dissected by erosion during the time required to form the later peneplane on the same rocks.

The writer wishes to emphasize the fact that the difference in elevation between Kittatinny Mountain and Schooley Mountain can be satisfactorily explained on the basis of a moderate amount of warping. A profile drawn over the tops of Kittatinny Mountain, Scott Mountain, Schooley Mountain, Watchung Mountains, and the Palisades reveals a uniformity of slope such as one might expect on the basis of the warping of a peneplaned surface. W. M. Davis (*3*, p. 355) remarks: "But it does not seem warranted to conclude that the peneplane theory is invalidated because certain peneplanes are now uplifted on a slant. It is no objection to the peneplane idea to say that the crest of Kittatinny Mountain is higher than the upland surface of the New Jersey highlands or that the crest of the Palisades is lower. It would be as extraordinary to find no slanting peneplanes as to find no inclined strata. Warped and faulted peneplanes are no more unlikely products of crustal deformation than warped and faulted sedimentary formations."

More recently Stose (*6*) invokes faulting to account for the difference in elevation of the Kittatinny and Schooley peneplanes. He says, "By this hypothesis the Schooley peneplane in the Piedmont is correlated with the Kittatinny peneplane in the Blue Ridge province and Appalachian ridges, the two parts of the peneplane being accounted for by post-Cretaceous normal faulting."

The profiles drawn by the writer from Kittatinny Mountain over Scott Mountain, Schooley Mountain, Cushetunk Mountain, and the Palisades do not show sufficient difference in elevation of the two surfaces to require any explanation other than a moderate amount of warping. The difference in elevation between Kittatinny Mountain and Scott Mountain is only 360 feet, a fall of 23.2 feet per mile, which is a comparatively low angle of slope. The fall per mile from Schooley Mountain to Cushetunk Mountain amounts to 37 feet per mile.

Since there appears to be no evidence of a peneplane surface lower than the Kittatinny in the ridge and valley section of eastern Pennsylvania which can be correlated with the Schooley surface, and none higher than the Schooley peneplane on South Mountain which can be correlated with the Kittatinny surface, it seems quite conclusive to the writer that

they are one and the same surface, which has been unequally warped and possibly faulted by uplift.

WIND GAP ELEVATIONS AND THEIR RELATION TO PENEPLANATION

The numerous wind gaps in the Appalachians mark the position of old stream valleys, the floors of which are now far above the adjacent country. They are significant because they mark the position of a drainage originally superposed across the ridges. Their presence is indicative of stream piracy, for they are clearly valleys crossing resistant formations through which no river now flows because of capture of the head waters by streams more favorably situated.

Some geologists are of the opinion that, since the position of a wind gap fixes an old stream level, wind gaps may have some relation to former base levels. A number of wind gaps at the same elevation would, according to this hypothesis, be sufficient evidence of a former peneplane.

Another feature upon which some place great reliance as evidence of peneplanation is the form of the wind and water gaps, since it may give valuable evidence as to the number and nature of erosion cycles. Although Arthur Keith was the first to emphasize the value of wind gaps as indicators of fluvial base levels, the chief proponent of these uses of wind gaps was Joseph Barrell (*1*), whose paper contains his arguments on the two points just noted.

E. B. Knopf (*5*) correlates what she interprets as residual erosion surfaces in the eastern Appalachian highlands with wind gap elevations. She says (p. 637): "The subaerial erosion cycle during which any one series of wind gaps was cut can be fixed only by the correlation of the wind gaps with composite slopes in the adjoining stream valleys and with remnants of erosion surfaces whose present altitudes show an evident relation to the base of the wind gaps."

In order to arrive at a definite conclusion as to the validity of Barrell's contentions, it is necessary to determine as closely as possible the relative elevations of the bottoms of the wind gaps. With this purpose in view the ridges in eastern Pennsylvania were profiled and the elevations of the gaps graphically compared.

On account of the great age of the gaps it is obvious, as pointed out by Barrell, that the present elevations of the bottoms of the wind gaps need not be the original ones. In the unglaciated area they may have been lowered from their original elevations by weathering and headward stream erosion in the same way that cols are produced, and in the glaci-

ated area the glaciers may have widened and deepened them by the ice scour. In some cases the bottoms of the wind gaps may have higher elevations than originally, due to accumulations of talus that have moved down their sides, thereby covering the original floor with a layer of debris. In the glaciated area the glaciers may have left deposits of till and fluvio-glacial material in the gaps. It is probable, however, that the great majority of wind gaps which occur in eastern Pennsylvania show no appreciable change as a result of glaciation.

If we consider all the ridges in eastern Pennsylvania, from Blue Mountain northward to the Allegheny Plateau, we find the wind and water gaps range in elevation from 280 to 1700 feet A. T. Of all the ridges Blue Mountain has by far the greatest number of wind and water gaps. A striking feature of the area is that Blue Mountain has so many large, conspicuous wind gaps, whereas they are lacking in Second, Third, and Peters mountains. In these ridges the wind gaps, if they may be so called, are shallow and occur only at the higher elevations. No wind or water gaps cross Broad Mountain, but both occur in Berry and Mahantango mountains to the north. Nescopeck Mountain near the Susquehanna also has a number of wind and water gaps. It appears that the proximity of the ridges to the larger streams is directly related to the number of wind and water gaps that cut through them.

In studying wind gaps it is difficult in some cases to decide whether a notch in a ridge is a wind gap or a col. The wind gaps listed were selected after the ridge crests were profiled and the gaps were seen in the field. Hence a careful selection was made, in the hope to eliminate the cols so far as practicable. The first table contains the elevations of all pronounced notches, a few of which may belong to the class of cols.

The statistics on wind and water gaps include all those notches cut in the ridges in eastern Pennsylvania, east and south of the Susquehanna River, and their extensions across the river to the points where they form the apices of the synclinal structures.

In Table I are listed all pronounced notches, a few of which may belong to the class of cols.

TABLE I

Number of Wind Gaps	Elevation above tide
1	1680-1700
3	1640-1660
1	1620-1640
1	1600-1620
1	1600
1	1580-1600

TABLE I—*Continued*

Nnumber of Wind Gaps	Elevation above tide
3	1560-1580
2	1540-1560
1	1550
2	1520-1540
2	1500-1520
1	1480-1500
1	1460-1480
4	1440-1460
2	1420-1440
4	1400-1420
1	1420
1	1400
4	1380-1400
1	1390
1	1340-1360
1	1320-1340
2	1300-1320
1	1305
1	1300
5	1280-1300
3	1260-1280
4	1240-1260
1	1220-1240
5	1180-1200
4	1160-1180
3	1140-1160
1	1120-1140
1	1109
3	1100-1120
1	1080-1100
1	1060
1	1040-1060
1	1020-1040
1	1018
1	981
2	940- 960
1	925
2	900- 920
1	880- 900
1	860- 880
1	800- 820
1	740- 760
1	720- 740

In Table II are included only those notches which are undoubted wind gaps.

TABLE II

Number of Wind Gaps	Elevation above tide
1	1620-1640
1	1560-1580
1	1520-1540
1	1420-1440
1	1400-1420
1	1390
1	1320-1340
1	1305
1	1300-1320
1	1300
2	1280-1300
1	1180-1200
1	1180
1	1160-1180
1	1109
1	1100-1120
1	1080-1100
1	1040-1060
1	1018
1	981
2	940- 960
1	925
2	900- 920
1	880- 900
1	860- 880
1	800- 820
1	740- 760
1	720- 740

All the water gaps in the area are listed in Table III.

TABLE III

Number of Water Gaps	Elevation above tide
1	1160
1	1140
2	1040-1060
1	1000
1	950
1	860
5	840- 860
1	760- 780
1	760

TABLE III—*Continued*

Number of Water Gaps	Elevation above tide
1	740- 760
2	720- 740
2	700- 720
1	680- 700
1	660- 680
1	660
2	640- 660
1	620- 640
3	600- 620
2	580- 600
2	560- 580
4	540- 560
1	520- 540
1	500- 520
3	480- 500
1	440
1	400- 420
1	393
1	380- 400
1	373
6	360- 380
1	320- 340
2	300- 320
1	280- 300

From the study of the first table containing all possible wind gaps, certain and doubtful, it is observed that the greatest number occur at the higher elevations. Some of these are shallow and of doubtful origin and do not appear in the second table, which contains only those concerning the origin of which there can be little doubt.

A glance at the tables shows lack of accordance in wind gap elevations. Their bottoms occur at all levels from 720 feet A. T. up to 1640 feet A. T. or up to 1700 feet A. T. provided we include the higher notches of less certain origin.

If we next consider the elevation of all the water gaps in the area, it is obvious that there is no accordance in their levels. An examination of Table III reveals water gaps at widely varying elevations. The large number of water gaps at 300 to 400 feet A. T. is due to the fact that the Susquehanna cuts through nearly all the ridges, and the elevations of its gaps range between those figures. Since the present surface of the area is by no means a peneplane, the water gaps cannot be said to be related to a peneplane or to mark a peneplane level. An even greater

diversity occurs in the elevations of the bottoms of the wind gaps. It would seem, therefore, that the wind gaps do not necessarily indicate the position of a former peneplane or peneplanes. Hence the value of wind gaps as indicators of former base levels would appear to be in the highest degree doubtful.

There may be some who are interested in the elevation of the wind and water gaps in a single ridge. Probably no better instance than Blue Mountain can be used further to test the validity of the hypothesis, for the reason that it has by far the greatest number of excellent gaps.

Table IV shows all the pronounced notches in Blue Mountain unoccupied by streams. A few of these may or may not belong to the class of cols.

TABLE IV

Number of Wind Gaps	Elevation
1	1560-1580
1	1550
1	1540-1560
2	1460-1480
3	1440-1460
1	1420-1440
2	1400-1420
1	1390
6	1380-1400
2	1360-1380
5	1320-1340
2	1300-1320
1	1305
3	1280-1300
1	1260-1280
3	1220-1240
2	1200-1220
2	1180-1200
3	1160-1180
1	1120-1140
1	1100-1120
1	1189
1	1080-1100
1	1018
1	981
1	940- 960
1	925
2	880- 900
1	860

Table V includes only those notches in Blue Mountain which are undoubted wind gaps.

TABLE V

Number of Wind Gaps	Elevation
1	1560-1580
1	1540-1560
1	1550
1	1460-1480
1	1440-1460
1	1420-1440
2	1400-1420
3	1380-1400
1	1390
3	1320-1340
1	1305
2	1280-1300
1	1260-1280
1	1220-1240
1	1180-1200
1	1180
1	1160-1180
1	1109
1	1100-1120
1	1018
1	981
1	925
1	900- 920
1	880- 900

The water gaps which cut through Blue Mountain are indicated in Table VI.

TABLE VI

Number of Water Gaps	Elevation
1	540-560
1	540
1	440
1	400-420
1	393
1	300-320
1	280-300

In Table VII are given the approximate depths, below the Schooley (Kittatinny) peneplane, of the undoubted wind gaps in Blue Mountain.

TABLE VII

Number of Wind Gaps	Feet
1	500
1	440
1	420
1	400
1	380
1	375
1	330
1	320
1	300
1	240
2	220
3	200
1	180
1	170
1	160
1	150
3	140
1	120
2	100
1	90
1	80
1	70
2	60
1	40

In Table VIII are given the approximate depths, below the Schooley (Kittatinny) peneplane, of the prominent wind gaps discussed in this report.

TABLE VIII

	Feet
Heckert Gap	500
Culver Gap	450
Pen Argyl Gap	420
Sterrett Gap	375
Deibler's Gap	340
Little Gap	330
Lehigh Furnace Gap	300
Wind Gap in Berry Mountain	300
Mitchell Gap	290
Van Nest Gap	250

TABLE VIII—*Continued*

	Feet
Wind Gap in Berry Mountain	230
Lamb's Gap	170
Miller Gap	170
Wind Gap in Berry Mountain	160
Wind Gap in Berry Mountain	150
Myer's Gap	130
Crane's Gap	120
Long's Gap	110

In Table IX are given the approximate depths, below the Schooley (Kittatinny) peneplane, of the water gaps discussed in this report.

TABLE IX

	Feet
Delaware Water Gap	1200
Lehigh Water Gap	1000
Susquehanna Gap through Second Mountain	930
Susquehanna Gap through Blue Mountain	900
Schuylkill Water Gap	900
Shickshinny Water Gap	900
Susquehanna Gap through Peter's Mountain	870
Klingerstown Water Gap	860
Nescopeck Water Gap	840
Weigh Scale Gap	800
Schuylkill Gap in Second Mountain	780
Shamokin Water Gap	780
Swatara Water Gap	770
Dornsife Water Gap	770
Mainville Water Gap	750
Ashland Water Gap	720
Pillow Water Gap	700
Wiconisco Water Gap	700
Swatara Gap through Second Mountain	700
Gap of the West Branch of the Schuylkill in Second Mountain	680
Susquehanna Gap in Berry Mountain	670
Indiantown Water Gap	640
Kohler's Water Gap	640
Susquehanna Gap in Mahantango Mountain	630
Swatara Gap in Sharp Mountain	600
Water Gap at Tamaqua in Second and Mauch Chunk Mountain	600
Schuylkill Gap in Sharp Mountain	600
West Branch of Schuylkill in Sharp Mountain	580
Gap of Lorberry Creek in Sharp Mountain	575
Gap in Rausch Creek in Sharp Mountain	560

TABLE IX—*Continued*

	Feet
Manada Water Gap	560
Gap at Tamaqua in Sharp and Pisgah Mountain	560
Gap at Tamaqua in Locust and Nesquehoning Mountain	550
Lykens Water Gap	550

The wind and water gaps in Blue Mountain were separately plotted on profile paper in order to show not only the irregularity in elevation but also the form of the gaps. The profile (Fig. 2) includes the water gaps and those notches which the writer considers to be undoubted wind gaps. A line was drawn through the bottom points of both wind and water gaps. This line may be called the "curve of irregularity." A glance at these curves is sufficient to justify the conclusion that no accordance of levels occurs for wind gaps, such as would indicate any relation to a base-leveled or peneplaned surface. The curve of irregularity is greater for the wind gaps than for the water gaps, and the latter certainly do not represent a peneplane.

According to Barrell's theory, wind gaps which are supposed to record a peneplane level should be more uniform in altitude than are water gaps in the mature stage of the current cycle. Since the water gaps of today have varying elevations and are known not to represent a peneplane level, the still more irregular wind gaps cannot be regarded as reliable evidence of former peneplane levels.

When the Schooley (Kittatinny) surface is used as the datum plane, the wind gaps (Table VII) in Blue Mountain reveal great irregularities in depth. It is very difficult to obtain the exact elevation of the Schooley (Kittatinny) peneplane, since it is a sloping surface and varies in altitude from point to point. The elevations can, therefore, be only approximate. Tables VIII and IX contain the data for the larger wind gaps and water gaps discussed in detail by the author in this report. The results in all cases indicate such great variations as to prompt the conclusion that there is no accordance in their elevations, and hence they can have no value as indicators of former base levels.

WIND AND WATER GAP ARRANGEMENT

If the profile of Blue Mountain (Fig. 1) is studied, it is observed that the gaps in general have a definite arrangement and occur in systems, each system representing a drainage unit. There is usually a larger wind or water gap, which is more or less centrally located. On both sides of the major gaps, at higher elevations, there often occur series

of wind gaps the elevations of which increase as one approaches the old divides preserved on the ridge crests. A profile drawn along the bottom of the wind gaps of each group indicates in most cases a slope toward the main gap. Thus each system of wind gaps can be considered as a former drainage basin.

Let us consider the nature of the drainage basins of the larger streams, the master streams of the northern Appalachians, which flowed on the Schooley (Kittatinny) peneplane. On the surface such as the Schooley (Kittatinny) we would expect the streams to have the arrangement described by Playfair, who stated that every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportional to its size, and that these branches form in the aggregate a system of valleys communicating with one another and having such a nice adjustment of their declivities that none of them join the principal valley either on too high or too low a level. We can consider the larger streams of the Appalachian region as the master streams from which numerous large tributaries extended. These large tributaries in turn branched out into subsidiary ones. The smaller streams have, therefore, a definite relation to the master streams and their elevations should increase toward the divides. A profile across any drainage basin on a peneplane would show a broad sag rising toward the divides from the trunk stream, and a longitudinal profile would show a gradually decreasing slope toward its mouth. The profile along the crest of Blue Mountain reveals cross sections of several such drainage units (Fig. 1). The general slope of the ridge crests is toward the larger streams, such as the Susquehanna and Delaware, while the local slopes are toward their tributaries. Drainage basins are somewhat spoon-shaped, and the valleys in each drainage unit that is farthest away from the master streams should have the greatest elevations. On a peneplane the valleys will be as near the same elevation as is possible at any time during the cycle of erosion, but even in extreme old age the stream valleys cannot be at the same elevations, since the drainage basin rises toward its periphery. We must imagine Blue Mountain crossed by the larger master streams, the Susquehanna, Schuylkill, Lehigh and Delaware, with their larger tributaries, which in turn have still smaller tributaries. Hence there must be major and minor drainage basins.

Let us examine the profile of the wind and water gaps of Blue Mountain (Fig. 1). On this chart are plotted all the notches, some of which might be interpreted as cols. What seems to be the striking thing about this chart? In general the smaller gaps are arranged around the larger

ones in systems. One of the best examples of such an arrangement is that between Pen Argyl Wind Gap and Lehigh Water Gap. Perhaps the finest of all the wind gap systems in the Appalachians is that located on Blue Mountain, west of the Susquehanna River. This we may designate the Sterrett wind gap system. The central and major gap of this group is Sterrett Gap, the elevation of which is 925 feet A. T. From it, at a much greater elevation, rises an ascending series of smaller wind gaps. Evidently Sterrett Gap was occupied by the master stream, the tributaries of which occupied the smaller wind gaps. The profile (Fig. 1) drawn along the crest of Blue Mountain reveals here a cross section of a complete drainage basin, the master stream of which was a tributary to the Susquehanna. Other similar wind gap systems occur, such as the Susquehanna, Swatara Creek, Schuylkill, Lehigh, Delaware, Pen Argyl and Culver. The most common arrangement of the wind gaps seems to involve a decrease in the elevations of their bottoms in the direction of the slope of the ridge crest toward the larger gaps. This is in harmony with the general notion of a peneplane, which should be an undulating surface rising toward the divides and descending toward the streams. Hence the most reasonable thing to expect is an increase in altitude of the wind gaps away from the master stream.

The uneven Schooley (Kittatinny) surface was of such a character as to indicate that superposition of the streams across the ridges probably did not take place on the Schooley (Kittatinny) peneplane. The slope of the ridges toward the streams further indicates that there was little chance of a shifting of the streams across the ridges, as postulated by Davis in the case of the Susquehanna. The evidence is clearly such as to indicate that the streams maintained their courses across the ridges during the Schooley (Kittatinny) cycle, and superposition, if it occurred, must have taken place during the previous cycle.

The prevailing opinion seems to be that there would be a decrease in the elevation of the wind gaps away from the master streams, since the streams farthest away had a longer period of time during which they could deepen their gaps before capture by the advancing subsequent streams. Since the wind gaps farthest away from the major gaps are in general the shallowest, another interpretation seems necessary. It is clear that the beheading of the transverse streams by the subsequents occurred so quickly that they did not deepen their gaps below that of their neighbor located nearer the trunk stream. It appears that subsequents within each drainage basin first accomplished the beheading of the transverse streams within that drainage basin. This took place

shortly after the uplift of the Schooley (Kittatinny) peneplane. Later, after capture of the transverse streams in each drainage basin had occurred, the subsequents which were most powerful and which possessed certain advantages pushed headward, invading neighboring drainage basins, producing wind gaps at lower elevations. The whole process of stream capture was a continuous one, that is, the subsequents were constantly pushing headward and shifting the divides away from the larger streams. The result would be that the present stream divides, with the exception of a few major ones, have little or no relation to the original divides which existed on the Schooley (Kittatinny) peneplane and which are still preserved on the ridge crests.

Shortly after the uplift of the upper level, the subsequent branches of the largest and most powerful streams beheaded the smaller, transverse streams which were struggling to cut down through the hard rock ridges. It was a struggle for existence and only the fittest survived. Those streams which profited by piracy of the streams at the higher levels were enabled to continue cutting their gaps deeper. Throughout the process of capture the number of water gaps decreased and the number of wind gaps increased. A gradual elimination of the weaker streams occurred and the survivors are those streams which occupy water gaps at present. The streams which benefited at the expense of the others were the larger tributaries of the Susquehanna, Delaware, Schuylkill and Lehigh rivers. The result of this process was a change; the shifting of the drainage to the subsequent streams which enjoyed the advantage of working headward on the less resistant rock formations, resulting in a drainage pattern less dendritic and more trellised.

A glance at Table I reveals the interesting fact that three-fourths of all the wind gaps occur above the elevation of 1100 feet A. T. If the undoubted wind gaps (Table II) are studied, the number above 1100 feet is not so large as when all are considered, the proportion being eighteen above to thirteen below. It appears that fewer wind gaps were produced during the latter part of the Harrisburg cycle. This is to be expected, since the divides became stable in the later stages of the cycle of erosion. The greatest shifting of divides should occur shortly after the uplift and warping of a peneplane, when increased gradients would result in rapid headward migration of the subsequents. Since the wind gaps are nearly all above the Harrisburg peneplane, the writer has come to the conclusion that wind gap production occurred mainly during the Harrisburg cycle and probably very little since that time. The divides established on the Harrisburg peneplane, it seems, have not shifted, for contours drawn on

this peneplane indicate that the present divides coincide with those established on the Harrisburg surface. In no case studied has the writer observed evidence of encroachment on neighboring drainage basins by streams the divides of which were established on the Harrisburg peneplane.

Let us suppose the uplift of the Schooley (Kittatinny) peneplane to have been continuous, gradual, or by a series of quickening movements, but with no halts long enough to allow peneplanation. In that case the region would have a long period of youth and the period from the time of uplift of the Schooley (Kittatinny) peneplane to the time of the formation of the Harrisburg surface would constitute only one cycle of erosion instead of a number of such cycles. The irregularities in the distribution of wind gap elevations weigh against the occurrence of peneplanes between the Schooley (Kittatinny) and Harrisburg levels, but rather favor the conception of a continuous process of stream capture with no long halts during which the land was peneplaned. In the course of any uninterrupted cycle of erosion we might expect the production of wind gaps to be most rapid early in the cycle, for the divides shift most speedily shortly after the uplift and warping. As the land surface passes into the later stages of the cycle, the divides shift more and more slowly until stability is reached.

We may conclude that the wind gaps in the Northern Appalachians are arranged in systems or groups about larger, central wind or water gaps, their elevations commonly increasing toward the ancient divides on the ridge crests. After the uplift subsequent streams within each drainage basin beheaded the streams crossing the ridges so quickly as to prevent the streams nearest the divides from deepening their gaps below those near the trunk stream. As the cycle of erosion progressed, the divides became increasingly more stable and wind gap production decreased. Hence the greater number of wind gaps occur at the higher elevations.

THE WIND GAPS

The Van Nest Wind Gap System

Van Nest Gap cuts through Scott Mountain at a point not far from the town of Oxford Furnace, N. J. An excellently paved highway goes through this gap, and beneath it a tunnel has been constructed through which passes the Delaware, Lackawanna and Western Railroad. This notch, which is rather small when contrasted with the larger gaps in the Northern Appalachians, can be seen to best advantage from the valley located southeast of Scott Mountain (Fig. 3). Viewed from that

Fig. 3.—Van Nest Gap from a point about one mile directly southeast.

direction it appears to be a broad, symmetrical sag with gentle, densely wooded slopes. As measured on the topographic map, it is about three-quarters of a mile wide across the top and about 250 feet deep. The bottom, 680 to 700 feet A. T., is above the Harrisburg surface and below the Schooley (Kittatinny) peneplane, which has an elevation near the gap of 900 to 1000 feet A. T.

Fig. 4.—Profile of Van Nest Gap, showing maximum angles of slope. Taken from the photograph above. Angles measured in the field.

When seen from a distance, the sides of the gap have a concave profile, in contrast to the wind gaps in the unglaciated portion of the Appalachians, which more often have a convex form. This may be due in part to glacial scour; there is evidence that the ice occupied the notch, for scattered glacial erratics and morainal deposits occur on its slopes and floor. Considerable amounts of bouldery soil appear to have accumu-

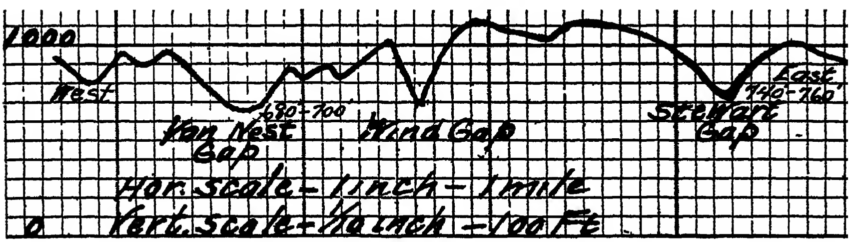

Fig. 5.—Profile of the Van Nest Wind Gap system, obtained from the topographic map.

lated on the graded slopes and on the bottom and these deposits doubtless are responsible in part for the form of the gap. The railway tunnel is cut through the bed rock, which is exposed in the notch at a point near the paved road. It would seem, therefore, that the morainal deposits and talus accumulations cannot be very thick, and that the present elevation of the bottom of the notch is nearly that of the original level.

The bed rock into which the gap is cut is a hard, homogeneous, granite gneiss. No ledges of rock, so conspicuous in the wind and water gaps in Blue Mountain, where sedimentary formations consisting of alternating hard and soft rock strata occur, are found in Van Nest Gap and for this reason no facets appear in its profile. The slopes have the maximum angle of about 18° on both sides and merge upward gradually into two knolls, one on each side of the gap.

From the valley southeast of Scott Mountain can be seen two more wind gaps. One, which has no name, lies about one mile northeast of Van Nest Gap; the other, known as Stewart Gap, is located at a point in the ridge still farther to the northeast. In contrast to Van Nest Gap, both notches appear to be more V-shaped and their floors are not so flat and are less rounded. They are similar, however, in that they appear to have densely wooded, graded sides which slope at angles of approximately 18°. The bottoms of all appear to stand well above the valleys, which lie to the northwest and southeast, and do not seem to be related to any peneplane surface; all that can be said is that they are cut below the Schooley (Kittatinny) peneplane, and are above the present valley level. The elevations and positions of the three wind gaps suggest that they were occupied by streams belonging to one drainage system. Stewart Gap has the highest elevation, 740 to 760 feet A. T., whereas Van Nest Gap is lowest, having an altitude of 680 to 700 feet A. T. This difference in altitude of three wind gaps, so close to one another and evidently all parts of one drainage system, is explained with difficulty by those who hold that wind gap elevations are related to peneplanes.

It is quite probable that Stewart Gap and its neighbor to the southwest were once occupied by tributaries, for they have a trend which relates the direction of stream flow with that of the trunk stream once flowing in Van Nest Gap. This stream continued its course south through the gap north of Port Colden, the elevation of which is the same as Van Nest Gap. The stream may have continued still farther south through Glen Gardner Gap. It is quite evident to one who has studied the three gaps that none of them could have been occupied by large streams comparable to the Delaware, Lehigh, Schuylkill and Susque-

hanna rivers. The stream of the gaps was small, possibly the size of Pequest River or even smaller.

E. B. Knopf (5) gives an interesting discussion of the drainage modifications in this area. On pages 654 and 655 she has pictured, by means of two diagrams, the drainage changes which she considers to have occurred. According to the diagram on page 655, Martin's Creek and the lower Delaware River constituted one stream during the period, which she calls the Sunbury subcycle of erosion. At the same time the upper Delaware River and Pequest River constituted another stream, which flowed through the Delaware Water Gap, Van Nest and Glen Gardner gaps. The present course of the Delaware is accounted for by the beheading of the Delaware-Pequest River by a tributary of Martin's Creek-Delaware River. The bend in the Delaware River above Belvidere would be, according to her hypothesis, an elbow of capture.

This sequence of events does not seem to fit the actual conditions. The Delaware River was already a large stream during the Schooley (Kittatinny) cycle of erosion and similar to the Susquehanna, Schuylkill and Lehigh rivers. These four streams were, as they are today, the master streams of Pennsylvania and New Jersey during the Schooley (Kittatinny) cycle. At a later period, during the Sunbury subcycle of erosion, they certainly were not smaller, but somewhat larger, for they were constantly extending their headwaters and enlarging their drainage basins. A study of Delaware Water Gap and Van Nest Gap in the field removes all doubt as to the size of the streams that occupied the two gaps. It seems very improbable that the upper Delaware, a larger stream, ever flowed through Van Nest and Glen Gardner gaps. Their size—that is, their width across the bottom—is such as to indicate that a small stream, even smaller than Pequest River, flowed through them. It seems more reasonable to the writer to believe that the Delaware River has maintained its course from a time prior to the Schooley (Kittatinny) cycle to the present.

In the opinion of the writer, it is likely that Stewart Gap and the smaller gap to the southwest were occupied by tributaries to a trunk stream which flowed through Van Nest Gap. This stream may have extended southward through the gap at Port Colden and the one called Gardner Gap. Subsequent streams from the Delaware, such as Pequest River, Pohatcong Creek and Musconetcong River, have worked headward on weaker rock, robbing the Van Nest stream of its drainage.

The arrangement of the wind gaps is in an ascending series from Van Nest Gap; that is, the gaps increase in altitude, Stewart Gap being

FIG 6.—East side of Culver's Gap from the northwest

the highest and farthest away from the trunk stream which occupied Van Nest Gap. Subsequent streams, which accomplished the piracy and produced the wind gap series, worked headward toward the northeast. It would seem that the wind gaps farthest away from the one occupied by the trunk stream would be the deepest, since the streams which occupied those gaps would have a longer period of time to cut

FIG 7.—Profile of the east side of Culver's Gap, taken from the photograph above. The angles were measured in the field and obtained from the same point at which the photograph was taken.

downward before piracy occurred. The actual conditions in the Van Nest wind gap system are contrary to the above theory. Stewart Gap is the highest one in the series, its altitude being sixty feet above that of Van Nest Gap. Evidently piracy occurred so rapidly that the streams farthest away, and originally higher, had insufficient time to deepen their valleys. The arrangement of tributary wind gaps in an ascending series from the main gap is not an uncommon feature in eastern Penn-

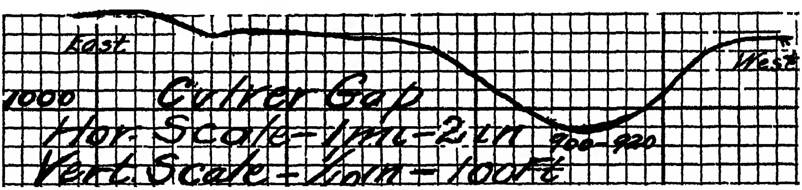

FIG. 8.—Profile of Culver's Gap, showing elevations From the topographic map

FIG. 9—West slope of Culver's Gap from the northwest

sylvania. It is clear that the former conception that the gaps farthest from the main gap are necessarily the deepest and have the lowest elevation is not necessarily true, for the reverse condition often occurs.

CULVER'S GAP

Culver's Gap, a large wind gap in Blue Mountain, is located near Culver's Lake, one of the important summer resorts in New Jersey.

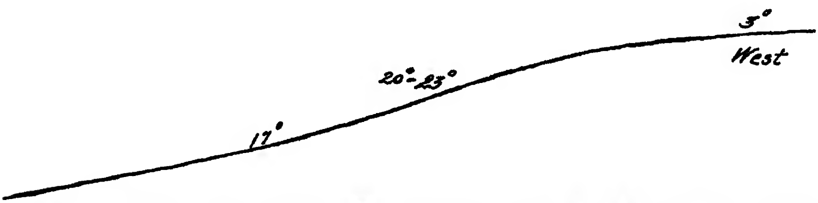

FIG. 10.—Profile of the west side of Culver's Gap, showing angles of slope. Taken from the photograph above. Angles obtained in the field.

Culver's Gap is very broad across the bottom and about two-thirds of a mile wide across the top. Its elevation is from 900 to 920 feet A. T. and its depth below the Schooley (Kittatinny) peneplane, which has an elevation of 1300 to 1400 feet A. T., is about 390 feet.

Unlike the other notches in Blue Mountain farther south, this gap has been heavily glaciated. There can be no doubt that the glacier occupied the notch, as morainal topography exists on its floor, and kame, till, and other glacial deposits are present in abundance. It is impossible to ascertain the depth of the glacial fill, for bedrock is not exposed in its floor. At Kittatinny Lake, located at the northern edge of the notch, a well record shows forty feet of glacial drift. The ridge crest of Blue Mountain, on both sides of Culver's Gap, has been scoured by the ice, as indicated by the grooves and striations which are numerous on the outcrops of the hard, Shawangunk quartzite. The ice evi-

dently moved nearly parallel or at a slight angle to the ridge; the chattermarks and striations indicate this trend.

The shape of Culver's Gap differs in outline from that of the other notches in the unglaciated section of eastern Pennsylvania. Its sides are slightly concave, whereas the normal profile in the unglaciated portion is more convex. This may be accounted for by the action of the ice, which scoured the sides of the valleys, giving them a concave outline. if the ice moved nearly parallel to the ridge, as indicated by the striations, the question arises as to whether the gap was scoured to any great extent by the ice. The expectation under those conditions would be stagnant ice and deposition in the gap. It is possible that the ice moved parallel to the ridge at one level but across it and through the gap at a lower level, since the direction of movement is determined largely by the trend of the elevations and depressions.

Blue Mountain, here as elsewhere, stands in relief as a result of the extremely resistant qualities of the Shawangunk quartzite and conglomerate. The lower slopes of the ridge are everywhere covered with soil and talus deposits, which have slumped down from the rock ledges above; in some places the bouldery soil covers even the ridge crest, which is quite narrow and sharp. Bold rock ledges are conspicuous on the sides of many of the gaps and especially so on the southeast side of Blue Mountain, whereas on the northwest side of the ridge, which is the dip slope, rock ledges are rare. These cliffs, so conspicuous throughout the Blue Mountain area, are outcrops of the Oneida and Medina conglomerate of Silurian age. The angle of dip of the formations in Blue Mountain varies considerably because it has been subjected to greater folding in some places than in others. On the ridge crest at Culver's Gap the Shawangunk conglomerate has a strike of about North 60° to 65° East. At this point the formation stands on end or is slightly overturned, the dip being a few degrees to the southeast. At the northern end of the notch, at Kittatinny Lake, about one hundred yards from the paved highway, in a rock quarry, the red shale outcrops of the Longwood formation dip at a high angle to the southeast.

A study of the ridge crest on both the east and west sides of Culver's Gap reveals the fact that bed rock outcrops seldom occur until one reaches a point near the top. Here a prominent ledge of rock, scoured and rounded by glaciation, produces a marked change in the angle of slope, being much steeper than the talus-covered, lower slopes of the gap. This prominent outcrop of rock can be seen on both the southeast and northwest sides of the ridge as well as in the gap, forming a steep

cliff in places. This steepening in slope produces an angularity in profile at about an elevation of 1300 feet A. T. Below this angle the sides of the gap have a slightly concave shape as if the ice had played a part in producing its outline. The hard quartzite and conglomerate, standing in a nearly vertical position, is flanked on both sides by weaker, less resistant shale formations, the red Silurian shales to the northwest and the Ordovician shales to the southeast. This in itself might produce changes of slope on the north and south of the ridge, but not those within the gap.

The form of Culver's Gap is described as follows: As observed from the northwest side of the mountain, the ridge crest on both sides descends by a very gentle angle of about 3° toward the gap. At about an elevation of 1300 feet A. T., a cliff occurs on either side and an angle appears in its profile. Below the cliff the slope is about 15° to 20° on the east side and about 20° to 23° on the west side. This slope flattens out toward the bottom of the gap and is slightly concave (Fig. 8).

It is difficult to determine what part glacial action played in modifying the original profile of Culver's Gap. When this notch is compared with Pen Argyl Wind Gap, we find that there are some very noticeable differences. The sides are steeper, there are more rock outcrops, there is little debris within the gap other than glacial material, the sides of the lower part of the gap are concave and the formations stand almost vertically. The steeper sides, concave outline, bedrock outcrops and lack of debris are due in part to glaciation. In both Pen Argyl and Culver's gaps, older, higher valleys with gentle slopes merge into the ridge crests very gradually, ultimately reaching angles as low as 3° or even lower. These older, higher valleys lie at or above an altitude of about 1300 to 1350 feet A. T., the approximate elevation of the angularities observed in their profiles, and are coincident with the courses of the streams which once occupied the gaps and represent the Schooley (Kittatinny) peneplane. This is more fully discussed subsequently in connection with the description of Pen Argyl Gap. Below the level of the older, higher valleys, there are no facets in the gaps that can be ascribed to stillstands of the land during which peneplanation occurred. The absence of structural facets in Culver's Gap is in harmony with the theory that all the angularities in the gap, except those produced where the ridge crests meet the gap sides, are due to ledges of hard rock outcrop where the angle of dip of the beds is low. The formations here stand nearly vertical and structural facets are absent in consequence.

FIG 11.—Culver's Gap from the Winona tourist camp south of Lake Culver. Observed from an angle.

Culver's Gap is of such width as to indicate that it was once the seat of a large stream. Glaciation has played such an important part in obscuring the pre-glacial drainage changes that it is difficult to give an accurate account regarding the history. The stream which accomplished the piracy was probably a pre-glacial one, occupying the valley now held by Big and Little Flat brooks. The original floor of the gap may have been higher than at present, glaciation having lowered it considerably; on the other hand, due to glacial deposition, its bottom may be higher now than it was originally.

To the south of Blue Mountain the elevation of the glaciated Harrisburg peneplane is about 900 feet A. T. The elevation of the gap, which is now approximately 920 feet A. T., probably stood at nearly the level of the Harrisburg peneplane. On account of the glaciation to which the gap has been subjected, it is difficult to determine accurately whether it stood above or below the general level of the Harrisburg peneplane.

FIG 12.—Ice-scoured Shawangunk conglomerate near the fire tower on the crest of Blue Mountain, west of Culver's Gap

Little Gap

Little Gap is located about five miles northeast of Lehigh Water Gap. It is about seven-tenths of a mile wide across the top and is very broad at the bottom (Fig. 14). The elevation of the ridge crest on the west side of the notch attains 1440 feet A. T. and the bottom of the gap stands at an elevation of 1109 A. T., the distance below the Schooley (Kittatinny) peneplane being 331 feet, which is its depth. The elevation of the notch above the Harrisburg peneplane to the south is about 400 feet.

The structure of the formations at Little Gap is like that at Lehigh Gap, located four miles southeast. The dip is toward the northwest and sufficiently low for the formation of structural facets.

At a distance the bottom of Little Gap appears to be gently rounded, but at close range, when one stands within the gap, the floor proves to be nearly flat. A walk over the ridge-crest trail, which branches from the road through the notch, takes one up the west slope. The ascent is at first gradual, becoming steeper as one approaches the point where the ridge crest merges into the gap. No rock outcrops or ledges appear on the west side, bouldery soil covering the bed-rock everywhere. Weathering and talus accumulations mantle the slopes and fill its bottom. How thick these deposits are it was impossible to determine; that they are rather thick is indicated by the absence of rock ledges or outcrops in the floor of the notch. The sides of Little Gap are of very gentle slope when compared with those of the water gaps. The water gaps of the Northern Appalachians as a rule are steeper-sided than are the wind gaps of the same area; and bold rock cliffs and ledges are more common. This is because the streams in the water gaps are constantly deepening their channels and sweeping away the weathering and talus accumulations. Since piracy took place, the wind gaps have been abandoned to weathering, whereas in the water gaps the slopes are being continually refreshed by erosion. The gentle slopes and broad, rounded bottoms of the wind gaps when contrasted with those of the water gaps, may lead one to the erroneous conclusion that there was an earlier cycle of erosion or peneplanation.

Slight benches due to concealed ledges occur in Little Gap, but the general slope of the sides is quite uniform. When viewed from the south, at Danielsville, the gap appears as a broad, symmetrical, gently rounded sag, no facets appearing in its profile. Study of the notch reveals a few irregularities in the outline, but nothing which can be interpreted as a facet due to peneplanation during a stillstand of the land (Fig. 14).

FIG. 13.—Little Gap as seen from a point south of Blue Mountain and west of Danielsville.

FIG. 14.—Little Gap from a point south of Danielsville

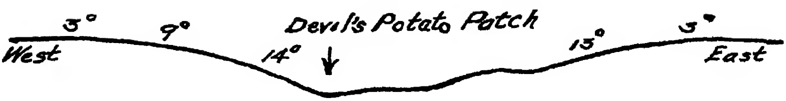

FIG. 15.—Profile of Little Gap, taken from the photograph above. Angles obtained in the field.

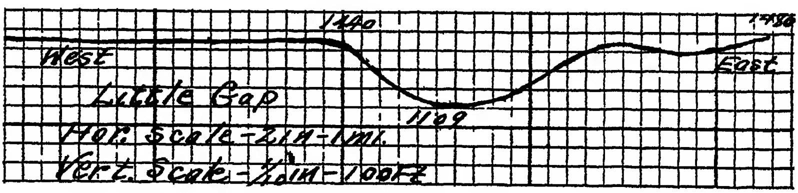

FIG. 16.—Profile of Little Gap, taken from the topographic map.

The ridge crest on the west side slopes toward the gap at an angle of about 3°, which increases to 9° and finally to 14°, the maximum degree of slope, grading by a continuously convex slope from one angle to the other (Fig. 15). The east side has a maximum angle of slope somewhat less than that of the west side, being about 13°. Near the bottom a slight hump appears in the profile, an irregularity due to a concealed ledge of rock somewhat more resistant to erosion. The ridge crest on the east side of the notch is broken by several shallow gaps (Fig. 1) but the general slope is downward, toward the notch. The profile of Little Gap indicates that the notch has been cut below a broad, shallow valley, which is revealed by the gentle slope of the ridge crest toward the gap. This slope is indicative of superposition of the stream which occupied Little Gap at a time prior to the Schooley (Kittatinny) cycle, for it is clear that the slopes of the ridge crest were developed during the cycle which produced the Schooley (Kittatinny) surface.

The sketches (Fig. 17) indicate the drainage changes which occurred in the Little Gap area. A fairly large stream originally flowed southward across Stony Ridge and Blue Mountain. After or during the uplift of the Schooley (Kittatinny) peneplane, an active subsequent stream, Aquashicola Creek, worked its way headward and diverted the headwaters of the stream crossing the ridges. Hunter Creek, a tributary of Aquashicola Creek, is the diverted portion of the stream, whereas Indian Creek, south of Blue Mountain, is the lower portion.

The writer walked over the flat area on the ridge crest west of Little Gap, in the hope of finding water-worn cobbles or gravels. Much weathered material, consisting of soil and angular boulders of quartzite and conglomerate occur on the mountain crest but, in spite of careful search, no water-worn cobblestones or gravels were discovered.

The Devil's Potato Patch

The Devil's Potato Patch is the name given by the people of the community to an expanse of huge, angular boulders of Shawangunk conglomerate, covering an acre or more, on the floor of Little Gap. Some of the boulders weigh tons and are of huge dimensions. The accumulation is so thick that the floor upon which it lies is not visible. In some places the rumble of flowing water, far below the surface, can be heard. There is a faint suggestion of smoothing of the rock surfaces here and there, which may be due to the action of running water; however, these indications are not sufficiently clear to make possible a definite statement.

It is rather remarkable that this boulder patch lies on a nearly flat

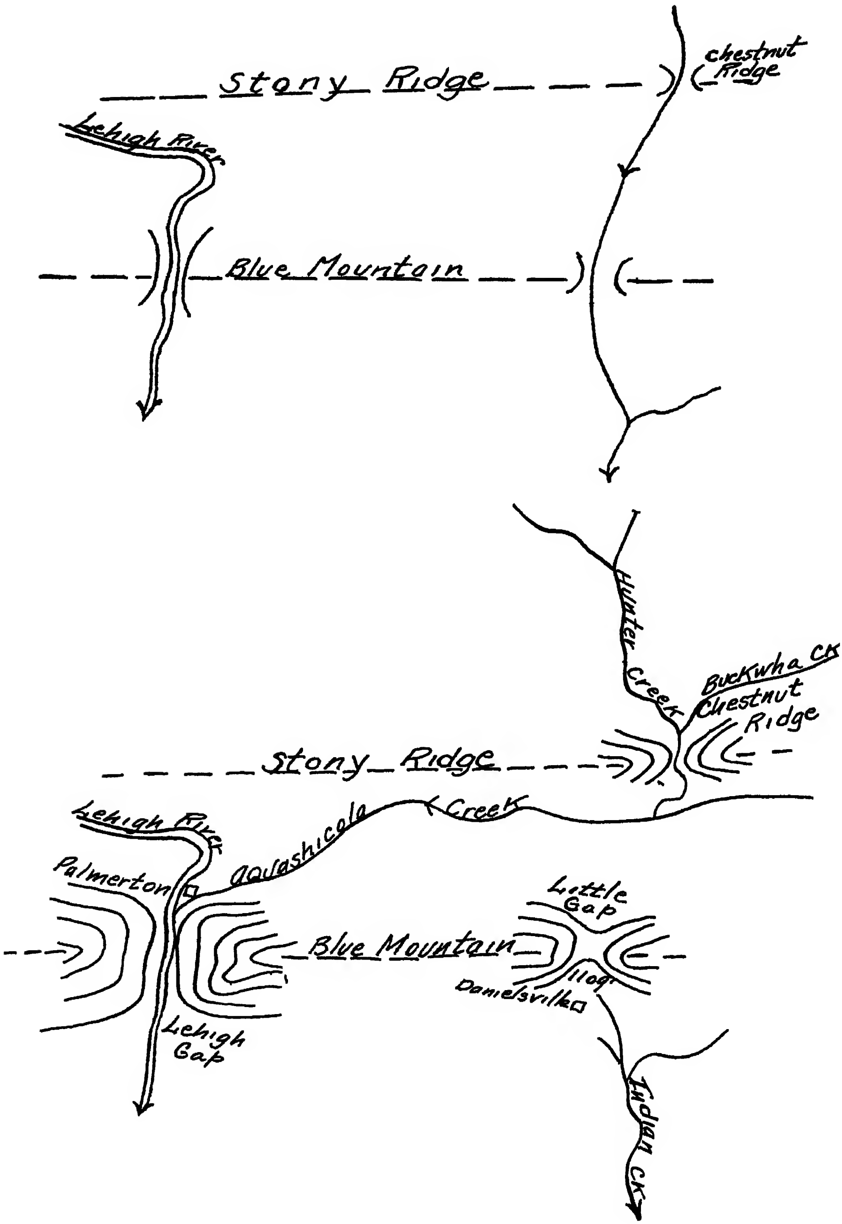

FIG 17 —The drainage before and after the piracy which resulted in the production of a wind gap (Little Gap)

Fig 18 —View of part of the boulder field called Blue Rocks Located about four miles east of the town of Hamburg and not far from the village of Lenhartsville

surface on the floor of a wind gap, the elevation of which is 1109 feet A T, about 400 feet above the Great Valley to the south The question arises as to the origin of this unique geological feature. Professor Bingham of Lafayette College has called similar boulder fields which occur on Blue Mountain "Rochiers" or rock glaciers, a term that implies a slow

Fig 19 —Boulder field in Little Gap Called by the people in the vicinity 'The Devil s Potato Patch

movement of the rock masses down a slope. The boulder patches are elongate and occupy what are certainly the bottoms of valleys. The enormous boulder field called "Blue Rocks," located four miles northeast of the town of Hamburg and about three miles northwest of Lenhartsville, is probably the largest of its kind. The area covered is said to be about thirty acres. The greatest width is attained near its lower end, where it is at least several hundred feet wide; its length exceeds a mile.

Numerous boulder patches of the Shawangunk conglomerate are present in that part of Blue Mountain, north of the Susquehanna River and south of the glaciated area. The rock constituting Blue Mountain, south of the Susquehanna River, is not so resistant as that to the north, and boulder fields are not so numerous or conspicuous. It is apparent that the rock to the south of the Susquehanna River weathers down to a soil more quickly than the rock north of the Schuylkill River, where boulder patches are more numerous and of greater extent. One of the principal factors to be taken into consideration, in the explanation of the boulder fields, is the extreme resistance to weathering of the Shawangunk quartzite and conglomerate. Through an enormously long period of time rock masses of this hard material have resisted weathering action and have by an extremely slow movement worked their way down the slopes of Blue Mountain, even to its foot, where the gradient is low. In the boulder field, "Blue Rocks," water can be heard flowing beneath the rocks. This is not uncommon since the boulder fields usually occur in valleys. Since all the rocks are angular and none are waterworn, it is evident that the rock masses have moved without the aid of water as a medium of transport. Soil and rock fragments have gradually worked their way down the slopes, gravity playing the major part in the movement.

A logical place for a boulder field such as the Devil's Potato Patch would be on the bottom of a wind gap, an abandoned valley. For an immensely long period of time, weathering has allowed the accumulation of great quantities of soil and angular boulders, as no stream occurs in the gap to remove the material. Gradual creep of the weathered debris toward the bottom of the notch has taken place. The natural escape of all drainage from the sides of the gap would be along the bottom, its lowest point. Here the water action beneath the boulders has been sufficiently effective to wash away the soil and finer material, leaving the larger resistant boulders which possibly are in some cases still gradually moving where the slope permits.

In a booklet advertising the Skyline Trail, Professor Bingham offers the suggestion that the Rochiers move on a substratum of clay. He says

"in confirmation of the theory it has been found that even on the steep hillside, the removal of the surface boulders reveals a thick deposit of clay." The present writer does not deny the presence of a substratum of clay but believes that it is not necessary for the movement of the rock masses, for it is a well known fact that boulders gradually work their way down slope, where, it is clear, no substratum of clay is present.

Pen Argyl Wind Gap

Pen Argyl Wind Gap is a deep notch in Blue Mountain, located just south of Saylorsburg, at the southwest corner of Hamilton township, Monroe County. This notch, referred to simply as "Wind Gap," is the finest example of a wind gap in the Northern Appalachians. Through it passes a paved highway which connects Stroudsburg with the towns in the Great Valley south of the ridge.

At Pen Argyl Wind Gap the Oneida rocks form the summit of Blue Mountain and by their great resistance have preserved that range so that its crest stands at an altitude of from 800 to 1000 feet above the soft measures to the north and south. The Oneida on the east side of the gap is deeply buried under its own debris. On the south slope of Blue Mountain it forms a cliff which, quite marked, is visible from the Great Valley. Its dip at Pen Argyl Wind Gap is toward the northwest and amounts to about 40°, an angle low enough to be favorable for the production of facets. The structure is nearly the same as that at Delaware and Lehigh water gaps (Fig. 74).

Pen Argyl Gap is about three-fourths of a mile across the top, whereas the floor is approximately one-eighth of a mile wide. From the ridge crest at 1400 feet A. T. to the bottom of the gap at 981 feet A. T. the vertical distance is 419 feet, which is also the distance below the Schooley (Kittatinny) peneplane.

Joseph Barrell (*1*) cites this gap as one possessing facets, due to halts in the general uplift of the land. He also has included a profile of Wind Gap (Fig. 25). The vertical scale is so much exaggerated as to make it appear sharply V-shaped and gives one an erroneous impression of its true form. The slopes of the gap are surprisingly gentle when contrasted with the steeper-sided, deeper water gaps in the region. Its slopes are covered with talus deposits and soil, allowing the growth of shrubs and trees to the very top. Great masses of angular fragments of Shawangunk conglomerate in places completely cover the bed rock. On the east slope of the gap bouldery soil and angular fragments of the conglomerate hide

FIG. 20.—Pen Argyl Wind Gap from the south. View obtained from a point near the Colonial Slate Quarry.

the bed rock so completely that no ledges are visible. These great talus deposits have accumulated since the occurrence of the piracy, which changed the water gap to a wind gap. One can ascend or descend the sides of Wind Gap without much difficulty and this is true of all the wind gaps in the Northern Appalachians. In the water gaps, however, this is

FIG. 21.—Pen Argyl Wind Gap from the north. View obtained from a point not far from Roscommon Manor.

almost impossible because of massive ledges and high cliffs of projecting bed rock. Even in the upper part of the Delaware Water Gap ledges are prominent, whereas in Pen Argyl Wind Gap their absence is conspicuous.

Barrell (*1*) would apparently correlate the slopes of Pen Argyl Wind Gap with the upper slopes of the Delaware Water Gap and other water

FIG. 22.—Profile of Pen Argyl Wind Gap taken from the photograph above. Angles measured in the field, at the point from which the photograph was taken.

FIG. 23.—Pen Argyl Wind Gap from the south.

gaps. He remarks on p. 340: "It is clear on comparing both the upper and lower slopes of the Pen Argyl gap with those of the gorges cut by the present through flowing rivers that all moderately resistant formations must have been thoroughly peneplaned during the cycles represented

FIG. 24.—Profile of Pen Argyl Wind Gap, taken from the photograph above. The angles were measured in the field.

by those slopes." The slopes of the wind gaps are gentler than the upper slopes of the Delaware Water Gap because the Delaware slopes are determined by vigorous erosion in the present cycle with the result that rock ledges are the controlling factors, whereas the wind gap slopes are de-

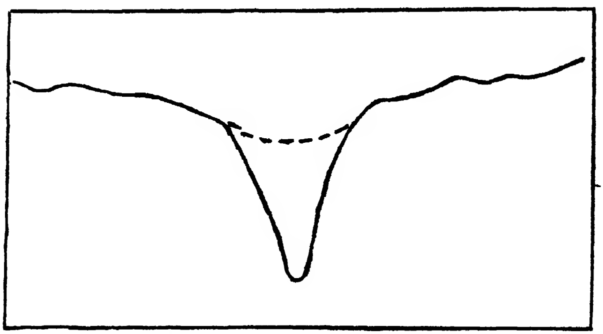

FIG. 25.—Barrell's profile of Pen Argyl Wind Gap, showing composite slopes. Exaggerated vertical scale.

termined by weathering since an earlier cycle. Barrell seems to think that the slopes are more gentle because they belong to an earlier cycle of erosion, in which all gap slopes were gentle, whereas it seems more probable that when capture occurred the notch was as steep as the present water gaps and that the difference in the angle of slope is due to the abandonment of the gap to weathering.

Viewed from a distance, the ridge crest on both sides of Pen Argyl gap is seen to slope faintly toward the notch. A sketch of the notch from the town of Wind Gap to the south (Fig. 24) displays a very gentle upper slope of about 3° or less on both sides toward the gap. This slope (Fig. 27) merges by a continuously convex profile into a slope which by measurement proves to be on both sides about 15°. A slight angle appears below this slope. The cause for this angularity is apparent when one walks along the road from the town of Pen Argyl to Wind Gap. Along the face of Blue Mountain at an elevation of about 1400 feet A. T. occurs a ledge of massive rock, probably the one so conspicuous at Delaware Water Gap and which there forms a steep cliff and a marked angle in the profile of the notch. When this ledge of rock is traced to the gap, a slightly rounded angle appears in line with it. Although not visible and concealed by talus deposits, the presence of the ledge is revealed by the angularity in the profile of the gap; on the west side of the notch its position is indicated by the slight bulge in line with it. Below this slightly rounded angle on both sides of the gap, at about 1400 feet A. T., the slopes have an angle of about 15°, which increases by a continuously convex slope to one of about 22° near the bottom of the notch. The change in slope is so gradual that, unless a straight edge is sighted along the slopes, it appears to be a continuous convex curve, the angle decreasing upward until it merges into the upland. When viewed from the north at a point near Roscommon Manor (Fig. 22), the outline of Pen Argyl Gap presents a profile similar to that seen from the south. The slight bulge at about 1400 feet A. T. appears to be more prominent on the east side. On both sides, from a gentle slope of about 2° to 3° on the ridge crest, it increases by a continuously convex curve to one of 10° to 15° and finally reaches a maximum of 22°. The bottom of the gap appears to be nearly flat or slightly rounded. No ledges of rock appear on the north side of Blue Mountain as the beds are dipping rather steeply toward the northwest.

Seen from the ridge crest on the west side, the cross profile of the east side of the gap shows a gentle north slope of the hard rock at the top of the mountain. This feature was also quite prominent on the cross pro-

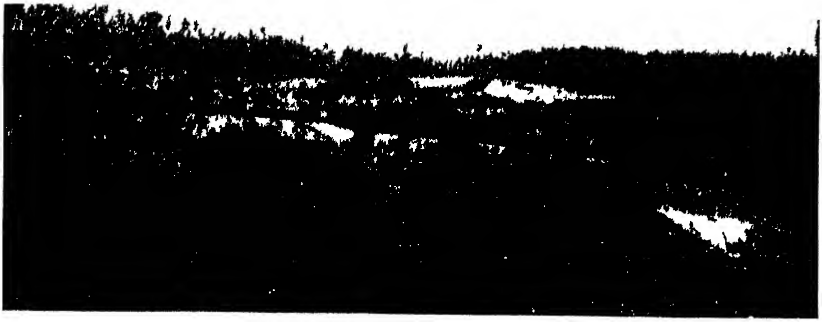

FIG. 26.—Pen Argyl Wind Gap as seen from a point four miles to the northwest. Note the long, gentle slope of the ridge crest toward the gap.

file of the east side of the Delaware Water Gap and bevels the structure at that place. A sharp angle can be seen at the point where the hard rock ledge appears on the south side of Blue Mountain.

Barrell (*1*) remarks: "The Pen Argyl wind gap shows two facets, as illustrated with exaggerated vertical scale in Fig. 9 [Fig. 25] of the present paper. The slope of the lower two thirds of the gap is about 18°, whereas for the upper one third it is about 8°." He goes on to say that "the upper and flatter slope does not appear to be a mere rounding off of the lower one, instead it belongs to the older and higher series of gaps and denotes a base level in an erosion cycle, which reached a far more advanced stage than did the cycle marked by the lower slopes of the gap. The restored elevation of this old base level is indicated by the dotted line in fig. 9 [Fig. 25], at about 1350 feet, which agrees with the upper set of wind gaps on Kittatinny ridge and also with the base level of about 1400

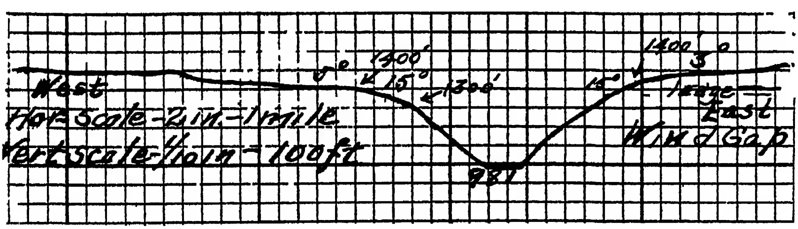

FIG. 27.—Profile of Pen Argyl Wind Gap, showing elevations. Taken from the topographic map.

feet found farther north." Barrell believed that the upper facet at the Pen Argyl Wind Gap represented a second cycle of erosion, which he correlated with the surface on Schooley Mountain and an upper system of wind gaps in Kittatinny Mountain, occurring at an elevation of about 1350 feet A. T. According to Barrell the Schooley base level is marked by an upper facet in Pen Argyl Gap and represents a surface cut below the Kittatinny level, which he maintained was an older, higher peneplane on the ridge crests. The present writer believes that the Schooley and Kittatinny peneplanes are one and the same and therefore the upper facet of Barrell in Pen Argyl Wind Gap cannot represent a second cycle of erosion.

The existence of the faintly descending slopes on the ridge crest on either side of Pen Argyl Gap indicates the presence of a high-level, broad valley on the Schooley (Kittatinny) peneplane, coincident with the course of the stream which once occupied the gap. Below this older, higher valley the present gap has been incised. All the facets in the notch below the slopes of the high-level valley are structural and therefore do not represent fluvial base levels. When the older valleys on the Schooley (Kittatinny) peneplane are studied, one finds that some are above and some below the 1350 feet A. T. level. In some cases a ledge of Shawangunk conglomerate occurs at about this elevation, producing an angle in the profile of the gap. This appears to be true at the Delaware, Lehigh and Pen Argyl gaps, all in Blue Mountain, where the Shawangunk conglomerate is found. Figure 26 shows that for long distances on either side the ridge crest, representing the upper Schooley or Kittatinny peneplane, descends faintly toward Pen Argyl Wind Gap, indicating that the stream which cut it was superposed in a cycle earlier than the Schooley (Kittatinny) and held its course throughout Schooley (Kittatinny) time.

The elevation of Pen Argyl Gap, which is 981 feet A. T., appears to be above the average elevation for the Harrisburg peneplane, which might be placed at about 700 feet. The Harrisburg surface rises toward the floor of the gap, although it may not merge into it. If the notch is above the peneplane level, the piracy which converted it from a water gap to a wind gap occurred during the Harrisburg cycle.

The bottom of Pen Argyl Gap is broad, probably several hundred feet wide, relatively flat with nothing showing but talus and some yellow soil, which looks like glacial debris. A short search in the yellow soil showed nothing that can be interpreted as erratics. The yellow soil appears to consist entirely of decomposed quartzite and shale which has slumped

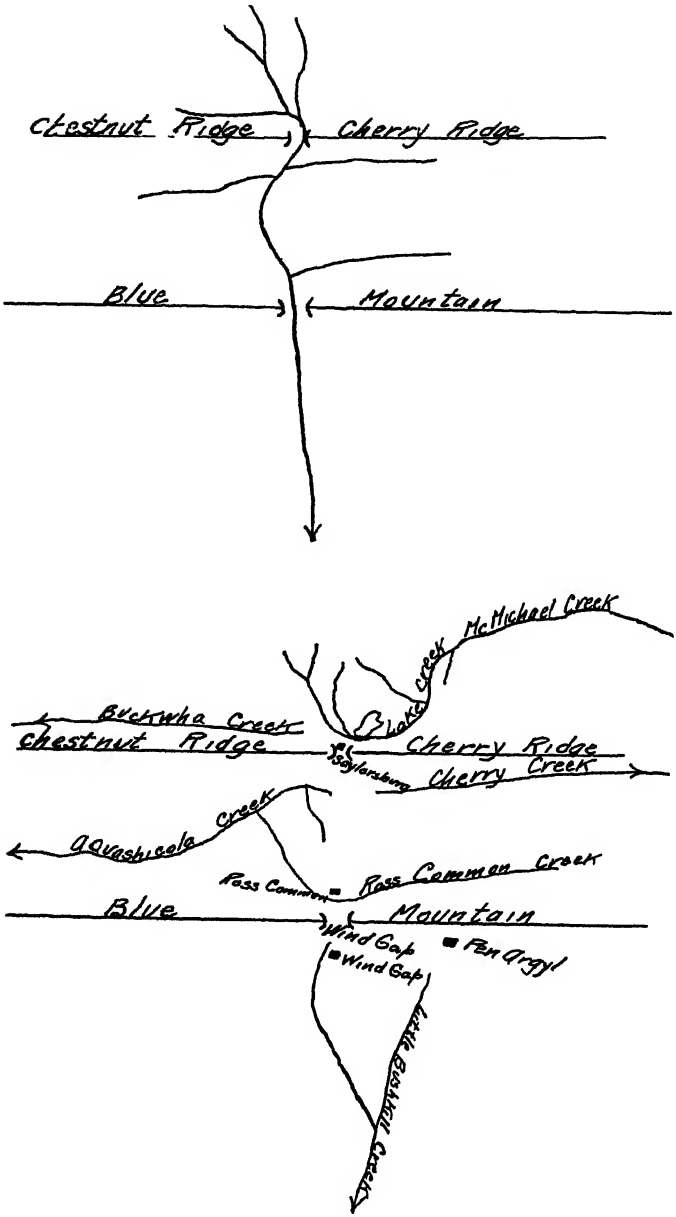

FIG. 28.—Sketches showing the drainage lines before and after the piracy which produced the Pen Argyl Wind Gap.

down from above. Some limestone fragments which were found may have been brought in as road material or might be glacial erratics. Certainly the evidence for glaciation in this gap is not convincing. The ridge crests and rock ledges show no striations, grooves or smoothed surfaces so characteristic of the rocks on the ridge at Culver's Gap. Even on relatively flat parts of the floor of the gap there is a gentle slope toward the center on both sides, indicating that the creep of the talus may have filled the bottom of the notch to a considerable depth. Shallow excavations some six feet or more in depth, and railroad cuts likewise, indicate that the floor is covered with rock debris, and some of the boulders seen in the excavation at a depth about ten feet are rounded as if waterworn. The shape of this gap cannot be assigned to glacial erosion, although it may have served as an outlet for the water from the melting ice which escaped southward when the ice filled the valley to the north.

The streams which accomplished the piracy, converting the water gap into a wind gap, were Aquashicola Creek, which flows into Lehigh River, Cherry Creek and possibly Lake Creek, a tributary of McMichaels Creek, both tributaries of Delaware River (Fig. 28). These streams, branches of two of the largest streams in the region, were able to work headward on the weaker rock formation and behead the smaller stream, struggling to cut its way down through the hard rock. The stream that formerly flowed through the gap was most likely Little Bushkill Creek, which is in line with it. The gap in Cherry Ridge at Saylorsburg suggests that after decapitation the beheaded portion of the stream continued cutting down through the ridge, its course being diverted later. About two miles northwest of Saylorsburg one can obtain from a hill near the road an excellent view of Wind Gap (Fig. 26). The top of this hill appears to be the Harrisburg peneplane rather poorly developed, much dissected and deeply trenched by later erosion. All over this surface are abundant rounded cobbles and gravels. Some of them are pitted by weathering. The elevation of these gravels is above 900 feet. They are certainly river gravels and it is possible that they may mark the course of the beheaded portion of the stream which flowed through Pen Argyl Wind Gap, although redistribution by ice and ice-born streams must be considered. As the gravels lie about 60 feet below the elevation of the floor of Pen Argyl Wind Gap, it is hardly possible that they mark the course of the stream when it flowed through the notch, but they may be related to the beheaded portion of this stream, the course of which was later disturbed by further piracy or glaciation.

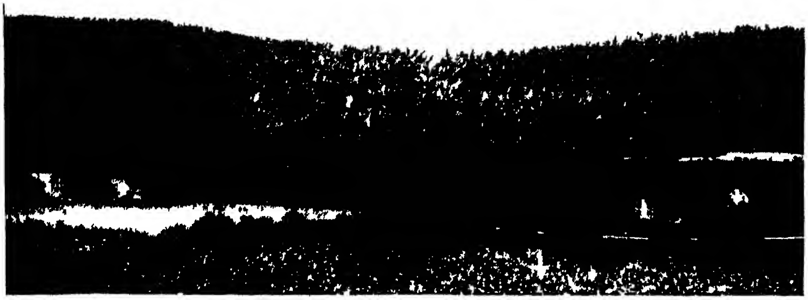

FIG. 29.—Lehigh Furnace Gap from the south. Note the boulder field on the slope of Blue Mountain.

FIG. 30.—Profile of Lehigh Furnace Gap, taken from the photograph below. Angles measured in the field.

FIG. 31.—Lehigh Furnace Gap from a point about one mile south.

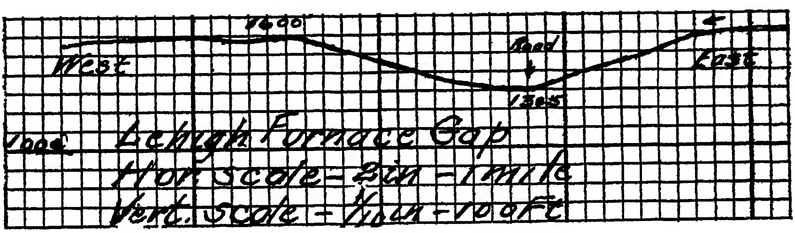

FIG. 32.—Profile of Lehigh Furnace Gap showing elevations. Taken from the topographic map.

Lehigh Furnace Gap

Lehigh Furnace Gap is located about four and one half miles directly west of Lehigh Gap. Through it passes an unimproved road which connects with the concrete highway at Ashfield, Pennsylvania.

The sequence of formations and structure is in general like that at Lehigh Gap, four and one-half miles to the northeast. The beds of Shawangunk conglomerate appear to dip 25° to 30° to the northwest.

Lehigh Furnace Gap has an elevation of 1305 feet A. T., about 300 feet below the summit of the ridge, which attains an elevation of 1600 feet A. T. on the east side. The width of the notch is about one mile across the top and its bottom, which is broad and rounded, is approximately one-tenth as much. The gap stands about 600 feet above the level of the Harrisburg peneplane, which has an elevation of about 700 feet A. T. in the Great Valley to the south.

From a point about one mile directly south (Fig. 29), the gap appears as a broad, rounded, shallow depression with slightly concave sides, the maximum angle of slope being but 12° on the west side and 9° on the east side. When seen from the town of Ashfield to the north of Blue Mountain, and directly in line with the gap, the slopes are the same as those obtained from the south.

The floor and sides of the notch are covered with a thick layer of rock debris. On the south side of the ridge, along the road, at a point about 100 feet below the bottom of the gap, a pit from which road material has been taken shows 15 feet of talus, soil and other weathered material, and no bed rock in sight. The Shawangunk conglomerate appears in places in great masses, and occasionally in boulder fields like the one in Little Gap but much smaller in extent. The sides of the gap have gentle slopes which are easily ascended, especially at the bottom where the surface seems nearly horizontal. They merge very gradually into the ridge crest by a continuously convex, broadly rounded curve. No ledges of rock outcrop on the sides, which appear to be graded and are everywhere covered by an accumulation of soil and angular boulders of the Shawangunk conglomerate. Although changes of slope or slight undulations are present in the profile of the notch, there is nothing that can be interpreted as a facet, either structural or due to peneplanation. It is probable that the irregularities in the profile are due to concealed rock ledges, since the low angle of dip of the beds at this place is favorable for their development.

The gentle slopes of the sides of the gap are due to the fact that the

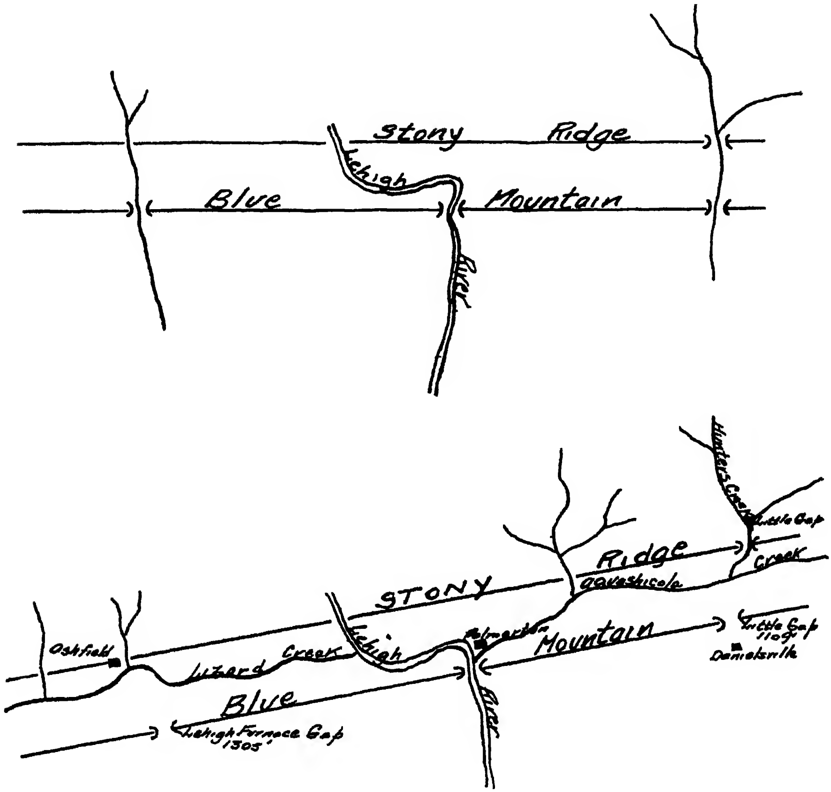

FIG. 33.—Sketches showing the drainage changes which took place in the vicinity of Lehigh Gap. Piracy by Lizard Creek and Aquashicola Creek has produced Lehigh Furnace Gap and Little Gap.

notch has been abandoned to weathering since the piracy converted it into a wind gap. The weathered materials and talus accumulations have collected on the slopes and the floor, because there is no stream constantly to deepen and widen it, thereby carrying away the debris which works its way down slope. Water gaps are characterized by steep, bold cliffs, numerous rock outcrops, and sides which meet the ridge crest and floor of the gap at sharper angles than in the case of the wind gaps. On the other hand, the wind gaps, long abandoned by the streams which once occupied them, have gentle slopes, few prominent rock outcrops and great accumulations of debris, which have gradually moved down slope covering the sides and the floor, producing the broadly rounded bottom profile so characteristic of them.

The stream which flowed through Lehigh Furnace Gap prior to its capture, was very probably a large branch of Trout Creek, a tributary to Lehigh River. Lizard Creek, a subsequent stream that had the advantage of working headward on weaker formations, beheaded the stream which was striving to cut its way down through the hard conglomerates and sandstone of which Blue Mountain consists. With Lehigh Water Gap the two wind gaps, Little Gap and Lehigh Furnace Gap, constitute a sort of unit. Both wind gaps were occupied by tributaries to the Lehigh River and both are about equally distant from the Lehigh Water Gap. But Little Gap is deeper than Lehigh Furnace Gap, the elevation of the former being 1109 feet A. T., whereas the latter is 1305 feet A. T. The stream in Lehigh Furnace Gap was probably the first to be beheaded, because Lizard Creek had a distance of but two miles to go from Lehigh River in order to complete the capture. On the other hand, Aquashicola Creek had to cover four miles before it could behead the stream flowing through Little Gap. We have in this case two wind gaps, occupied contemporaneously by two streams comparable in size, both tributaries to the same stream and nearly the same distance from it. If wind gap elevations are related to peneplanes, it is difficult to explain the difference in elevation of the two gaps. According to this theory Lehigh Furnace Gap at 1305 feet A. T. marks a peneplane surface at that elevation, and Little Gap at 1109 feet A. T., which is 196 feet lower, still another. It seems almost inevitable that Aquashicola Creek, fully as large or even larger than Lizard Creek, would have beheaded the stream flowing through Little Gap, at about the same time or shortly after the capture had taken place at Lehigh Furnace Gap. It is difficult to believe that the Little Gap stream survived through another complete cycle of erosion before beheading took place. Such a survival would imply that either Aquashicola Creek accomplished the piracy which produced Lehigh Furnace Gap, or that it was a small stream and had not yet worked headward sufficiently far to behead the Little Gap stream.

The Sterrett System of Wind Gaps

Blue Mountain, west of the Susquehanna River, contains a number of good wind gaps. The largest and by far the best of the group is Sterrett Gap, which occupies a central position. The names of the gaps, taken in order, from the Susquehanna River westward, are Lamb's, Miller's, Myer's, Sterrett, Crane's and Long's gaps. These are the names appearing on the United States topographic map (New Bloomfield Quadrangle).

FIG. 34.—Sterrett Gap as seen at a slight angle from a point about one mile south of Blue Mountain.

When Blue Mountain is seen from the Cumberland Valley to the south and west of the Susquehanna River, its crestline, set off sharply against the sky, reveals to best advantage this system of symmetrical wind gaps. Sterrett Gap, comparable to Pen Argyl Wind Gap in size and symmetry, dominates the group because of its greater depth and width.

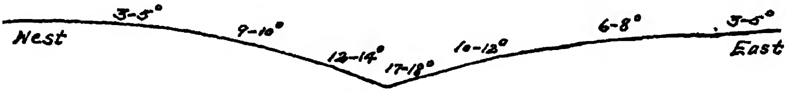

FIG. 35.—Profile of Sterrett Gap as seen from a point south of the gap and in line with it, showing angles of slope.

The structure of the region (Perry County) is quite simple as a whole, and stands as the typical district of the Appalachian Mountain belt. Two great basins, cut across by the Susquehanna and Juniata rivers, sink eastward to receive the two lobes of the fish-tail of the southern anthracite coal field in Schuylkill County, and rise westward so as to bring to the

FIG. 36.—Sterrett Gap. Another view from a point south of Blue Mountain.

surface concentric ellipses of successively lower formations, the mountain outcrops of which form the southern, western and northern borders of the county. The Pocono sandstone ridges, Peter's and Cove mountains, form the apex of a syncline to the north.

The Medina and Oneida sandstone beds outcrop in the floor of Sterrett Gap. Their strike is nearly east-west and they dip at a high angle, 75° to 80° to the northwest. At Lamb's Gap the sandstone beds dip at an angle of about 80° in the same direction.

The altitude of the bottom of Sterrett Gap is 925 feet A. T., which is about 400 feet above the level of the Harrisburg peneplane to the south. At the top the width of the notch is about one mile, and its depth below the ridge crest is about 375 feet, which is approximately its distance below the Schooley (Kittatinny) peneplane.

Seen from the south (Fig. 34) Sterrett Gap presents a somewhat different picture than the Pen Argyl and Culver wind gaps. It is more V-shaped and its bottom appears to be somewhat narrower and not so flat. Looking at the profile from the south, at a point in line with it (Fig. 35), we note that its uniformly convex sides slope at low angles, a feature common to all the wind gaps in the Appalachians. The maximum slope on the east side of the notch is from 17° to 18° near the bottom, and about 6° to 8° or less farther up, grading from one angle to the other by a continuously convex slope. On the west side of the gap the maximum slope reaches 12° to 14° near the bottom, and grades by a convex slope into one of 9° to 10° near the top. Both sides grade by a convex slope into the ridge crest, which has a faint slope toward the gap of about 3° to 5°.

The sides of Sterrett Gap are covered with debris to the top, and even the ridge crest has a cover of stony soil. The great masses of angular boulders, so common on the slopes of Pen Argyl Wind Gap, are absent here. The Medina and Oneida sandstones appear to weather down more readily, and "rochiers" or boulder fields do not occur on the slopes of Blue Mountain. Where they do occur to the northeast, their presence seems to be attributable in part to the more resistant character of the formations.

Sterrett Gap, whether viewed from a distance or from a point close at hand, does not show facets. This condition is in harmony with the theory of the writer that the facets in the wind gaps and water gaps are structural, because they do not occur where the formations stand at a high angle.

The other wind gaps in Blue Mountain, west of the Susquehanna River, can be treated as a group, for they exhibit the same characteristics. They are broad, symmetrical, shallow sags, the slightly convex sides of which have an average slope of more than 5° and less than 10°. Their average width across the top is about two-thirds of a mile, and all are less than 300 feet deep. Thick soil deposits cover their sides and bottoms everywhere, and rock ledges are absent. There are no facets in their profiles and the sides seem to grade by continuously convex slopes into the ridge crest, which appears to slope gently toward the gaps.

A study of the profile of the ridge (Fig. 37) shows that the general slope of the crest is toward the Susquehanna River, the highest point being where Blue Mountain ends. Where two ridges meet at the apex of an anticline or syncline, the greater thickness of the resistant formation causes the point at the apex to have a higher elevation, due to the fact that it was more slowly lowered by erosion. This is generally true in the ridge and valley section of eastern Pennsylvania. At the apex of the syncline, at the end of Blue Mountain, the altitude of the ridge attains 1500 feet A. T., whereas the elevation is about 1160 feet A. T. at the Susquehanna River. The difference in altitude is about 450 feet and indicates that there is a decided slope of the ridge crest eastward toward the Susquehanna. This is the slope of the Schooley (Kittatinny) peneplane toward the river, for the ridge was beveled by the old surface. It is quite evident that the Susquehanna occupied a distinct valley, so far below the divides preserved on the ridge crests that it is difficult to explain how the streams could have shifted their positions and become superposed across the ridges. The lateral shifting of the Susquehanna from a position west of the apex of the syncline to its present position on the Schooley (Kittatinny) peneplane, as postulated by Davis, seems impossible when the height of the divides and the depth of the stream valleys on the Schooley (Kittatinny) surface are considered. The slope of the ridge crest is everywhere toward the streams and the higher points which constitute the divides are so far above the streams that it seems very improbable that much shifting took place, that is, sufficient shifting to allow the streams to become superposed across the ridges. The evidence does not support the assumption that the Schooley (Kittatinny) peneplane was so flat as to allow much shifting of the stream courses, but seems to favor superposition across the ridges at a time prior to the Schooley (Kittatinny) cycle.

A description of the Sterrett drainage basin as it appeared on the Schooley (Kittatinny) surface is necessary for an understanding of the

sequence of events which followed in the production of the Sterrett system of wind gaps. The Sterrett drainage unit was one of the many which existed on the Schooley (Kittatinny) peneplane. The major or trunk stream was a tributary of the Susquehanna and flowed in a high-level, broad, shallow valley, coincident with Sterrett Wind Gap. The major tributaries to the trunk stream occupied the larger wind gaps located on both sides of Sterrett Gap (Fig. 38). Blue Mountain probably existed as a low, elongate monadnock on the Schooley (Kittatinny) peneplane. The streams of the Sterrett drainage unit, where they crossed the ridge, might therefore have occupied broad, shallow gaps, the ridges of which sloped from the divides preserved on the ridge crests and produced during the Schooley (Kittatinny) cycle of erosion.

The fact that there is a general slope of the ridge crest from the apex of the syncline west of Sterrett Gap to the Susquehanna River is in harmony with the theory that the Sterrett drainage unit was a part of the Susquehanna system. Another feature is the long, gentle slope of the ridge crest downward toward Sterrett Gap. On the west side of he notch the slope begins at the apex of the syncline, and on the east side from a point at an elevation of 1360 feet A. T. that is located about a mile west of Miller Gap. The latter point marks the position of an ancient divide on the Schooley (Kittatinny) peneplane. East of this point the ridge crest slopes toward the Susquehanna River. It would seem that the high level stream, coincident with Sterrett Gap, was a fairly large one, for the slopes of the ridge crest toward the notch are long.

The drainage pattern of the Sterrett system on the Schooley (Kittatinny) surface was dendritic and the land surface sloped very gently toward the trunk stream and southward. In any drainage system the larger tributaries nearest the trunk stream have the deepest valleys and those smaller tributaries on the periphery of the drainage basin are shallowest.

The profile (Fig. 37) is a cross section of the Sterrett drainage system. The notches on both sides of Sterrett Gap increase in altitude in a direction away from the stream, Myer's Gap, 1180 feet A. T., being the highest on the east, and the notch west of Long's Gap, 1420 feet A. T., the highest on the west. The present elevations of the wind gaps are, of course, not the original ones on the Schooley (Kittatinny) surface, for they were deepened by subsequent erosion. The conditions which present themselves in the Sterrett wind gap system and others in the Appalachians are in accordance with the general conditions which occur on a peneplaned surface. The land would slope gently toward the larger streams and the highest valleys should be on the periphery of the drainage basins.

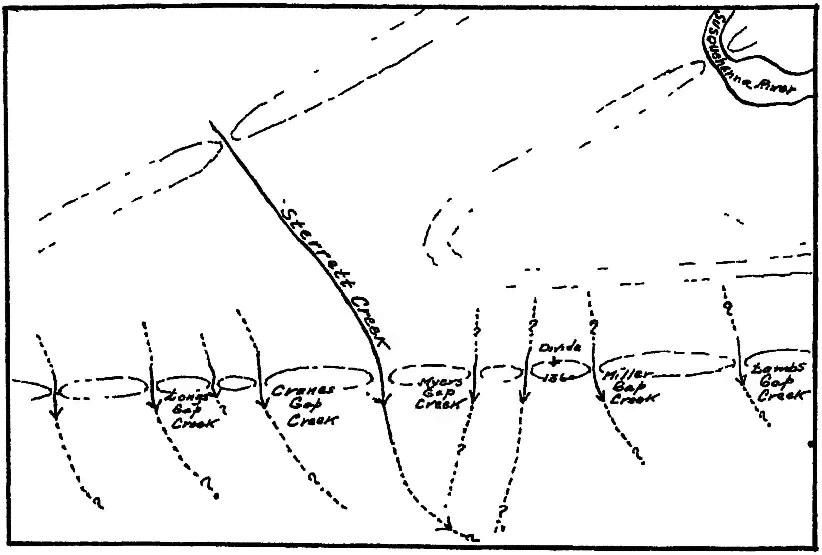

FIG. 38.—Diagram showing possible arrangement of the streams in the Sterrett drainage system on the Schooley (Kittatinny) peneplane.

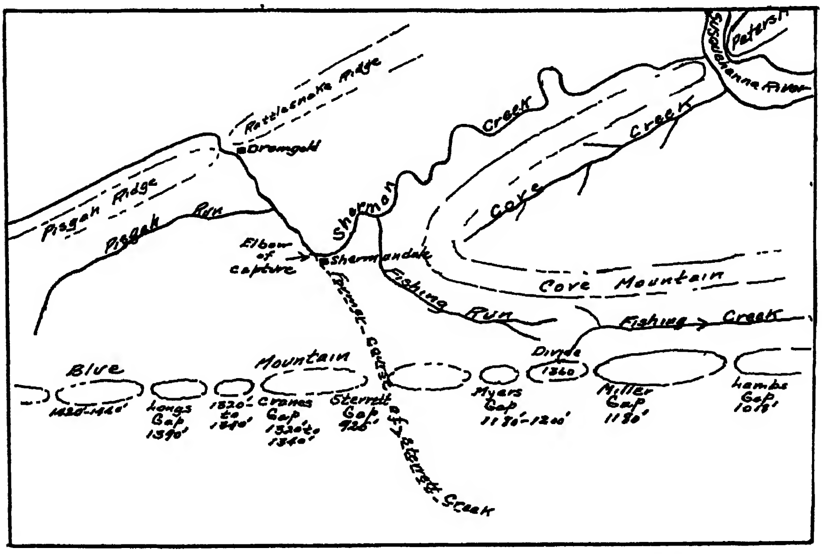

FIG. 39.—Diagram showing the present arrangement of the streams in the vicinity of Sterrett Gap after piracy occurred to produce the wind gaps.

After the uplift which ended the Schooley (Kittatinny) cycle, the streams in the Sterrett system cut down their channels. Subsequent streams began to work their way east and west of Sterrett Creek on the weaker Clinton shales, north of Blue Mountain, and beheaded the tributaries crossing the ridge, thereby producing wind gaps. We might expect the wind gaps farthest from the trunk stream to be the deeper, because they were the last to be beheaded, but as a matter of fact, we find instead an ascending series of wind gaps. The explanation is that on the initial Schooley (Kittatinny) peneplane the stream valleys all had elevations proportional to their distance from the trunk stream. Consequently the notches farthest from the Sterrett Gap stream are higher, because they were initially higher. Apparently the subsequent streams from the trunk stream worked headward so rapidly that those streams farthest away and initially higher could not deepen their valleys below the level of the wind gaps nearer the trunk stream before capture took place. It may be noted that Myer's and Crane's gaps are respectively 255 and 395 feet higher than Sterrett Gap. This means that the capture of the tributaries which crossed the ridge was completed when Sterrett Gap was considerably higher than it is now.

Finally the creek occupying Sterrett Gap was the sole survivor of the system of streams which crossed the ridge. Later Sherman Creek, an active subsequent tributary of the Susquehanna River, worked headward to a point near Shermandale and beheaded Sterrett Creek. The right-angled bend in Sherman Creek may be an elbow of capture. However, this is not the only possible explanation for the bend in the stream. The structure is that of a syncline and a stream would, after crossing Pisgah Ridge, flow down the dip of the formation and turn sharply to take a course parallel to the axis of the syncline.

It is possible that the streams occupying all the gaps in Blue Mountain, west of the Susquehanna, were tributaries to Conodoguinet Creek. This would make Sterrett Creek a large tributary of Conodoguinet Creek instead of the trunk stream of a drainage system. The streams which accomplished the piracy would be, according to this theory, Sherman Creek and its tributaries and Fishing Creek, a small tributary to the Susquehanna River. The latter theory does not explain the ascending series of wind gaps on either side nor the fact that Sterrett Creek was the last to be beheaded, since it has the lowest elevation.

It has been suggested that the streams across the ridges flowed north instead of south. There is little in favor of such an hypothesis, although

it is possible that the drainage may have been locally northward toward the axis of the syncline.

The question arises as to the cycle in which the capture producing the wind gaps took place. The evidence is in favor of continuous down-cutting from the Schooley (Kittatinny) level to the Harrisburg surface, without any stillstands of the land sufficiently long for peneplanation to be consummated. The uplift ultimately ceased long enough to allow the development of the Harrisburg peneplane. Sterrett Gap stands more than 40 feet above the level of the Harrisburg peneplane, which has an elevation of about 500 feet (in the Great Valley) south of Blue Mountain. Since there are no facets in the wind gaps or other evidence for peneplanation between the Schooley (Kittatinny) and Harrisburg levels, such as accordance of wind gap elevations or remnants of peneplane levels, the writer believes that the wind gaps were produced during the Harrisburg cycle of erosion. This would mean that the land surface was lowered the distance from the ridge crests to the Harrisburg peneplane level during the Harrisburg cycle. There appears to be evidence in this region for but two peneplanes, the Schooley (Kittatinny) and the Harrisburg.

Heckert Wind Gap

About three miles northeast of Linglestown, Blue Mountain is cut through by a broad sag called Heckert Gap (Fig. 40).

The structure at Heckert Gap is like that at the Susquehanna River, where the strata are overturned and dip about 70° to the southeast. The Shawangunk conglomerate and sand stones are here, as elsewhere, the resistant beds responsible for Blue Mountain.

Heckert Gap is about two and one-half to three miles wide at the top, if the long gentle slopes on each side are included. The part of the gap cut below the long, gentle slopes, and which is occupied by the upper portion of Beaver Creek, is about two-thirds of a mile wide and about 320 feet deep. The total depth of the gap, if the upper slopes are included, is about 660 feet and its elevation at the bottom is about 680 feet A. T.

The form of Heckert Gap is unlike that of any other in the Northern Appalachians. It is rather difficult to say whether it should be classed as a wind gap or a water gap. The writer is of the opinion that it should be classed with the wind gaps. The evidence seems to point to piracy by Fishing Creek, causing the abandonment of the gap by the greater part of upper Beaver Creek. A small tributary of Beaver Creek now flows through the southern part of the gap, but does not extend across the

FIG. 40.—Heckert Gap from the south.

divide into the valley to the north, now occupied by Fishing Creek. The profile (Fig. 42) shows the valley cut by Beaver Creek but, if it were drawn along the divide, the steeper, inner, V-shaped portion would not be so pronounced and the slope would be more gentle, a feature characteristic of wind gaps. The photograph (Fig. 40) shows the skyline profile, which has the outline of a wind gap. The sides of Heckert Gap slope very gently, the east side having a maximum angle of 15° and the west side one of only 5°. No rock outcrops are present in the notch and its sides appear to be graded, debris covering the bed rock everywhere. There

FIG. 41.—Profile of Heckert Gap, taken from the photograph above. Angles obtained in the field from a point directly in line with the gap.

are no facets in the profile of the gap but its outline appears to be irregular (Fig. 40).

Blue Mountain has an elevation of more than 1600 feet A. T. near the Delaware and Lehigh water gaps, whereas the elevation in the vicinity of the Susquehanna River is about 1350 feet on the east side and about 1150 feet on the west side of the gap. The ridge crest slopes toward the Susquehanna River from a point thirteen miles west of Schuylkill Gap,

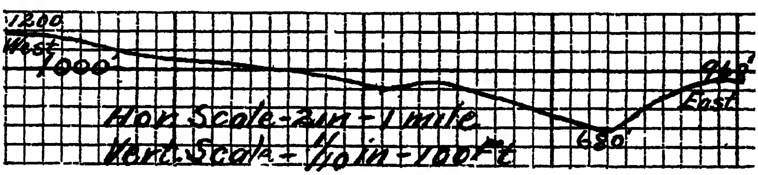

FIG. 42.—Profile of Heckert Gap, showing elevations. Taken from the topographic map. The profile, Fig. 41, represents the sky-line, whereas the present profile is drawn across the deepest portion of the gap.

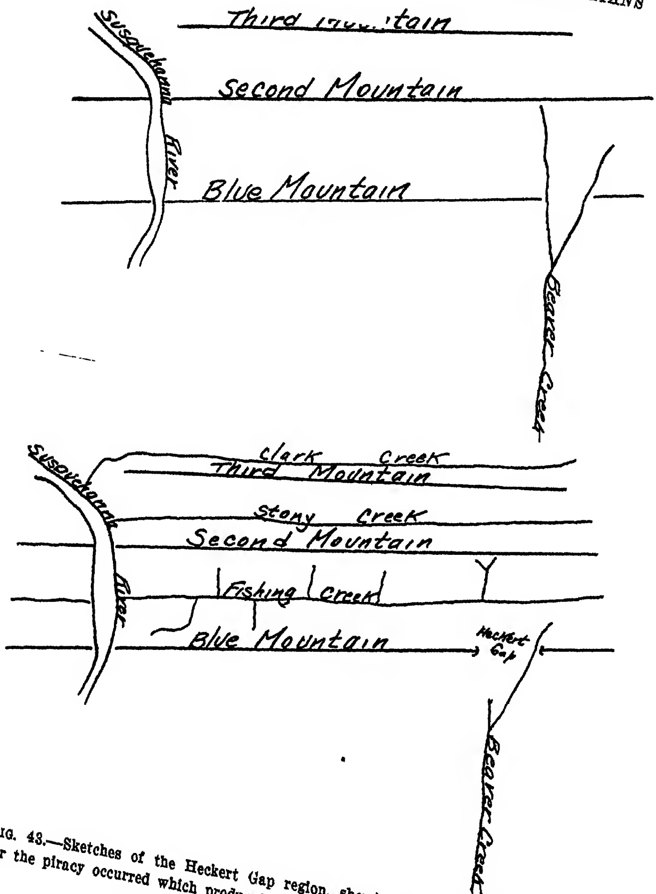

FIG. 43.—Sketches of the Heckert Gap region, showing the conditions before and after the piracy occurred which produced the gap.

where the elevation is 1680 feet A. T. The decrease in altitude is due to the fact that the slope of the ridge crest is toward the major streams and indicates superposition of the streams across the ridges at a time earlier than the Schooley (Kittatinny) cycle and that they held their courses throughout Schooley (Kittatinny) time. The point at 1680 feet A. T. marks the divide between the Susquehanna and Schuylkill drainage basins, established on the Schooley (Kittatinny) peneplane. The slope of the peneplaned land surface would be toward the trunk stream in any drainage

basin. These slopes are preserved on the ridge crests, the length of the slopes being proportional to the size of the drainage basins.

The stream which cut Heckert Gap was a small one and the question arises as to whether it extended northward over the ridges during the Schooley (Kittatinny) cycle. There is no evidence that it did, for no wind gaps occur in Second Mountain in line with Heckert Gap.

Wind Gaps in Berry Mountain

Several excellent wind gaps are present in that part of Berry Mountain which extends from the Susquehanna River eastward to a point a few miles beyond the town of Elizabethville.

Berry Mountain is composed of the Pocono sandstone, which dips at a high angle, from 60° to 70°, to the northwest.

Viewed from the valley to the north, the ridge presents a series of very symmetrical, broad, rounded sags. Four of these, and perhaps a few more, appear to be true wind gaps. The distances of three of them from the Susquehanna River in an easterly direction are respectively one and one-quarter, two and three-quarters, and five miles; the fourth is located about one mile southwest of Elizabethville.

The whole series of gaps in Berry Mountain can be treated as a unit. Their depths vary from 100 to 290 feet below the ridge crest, and their heights above the Harrisburg peneplane, in the valley to the north, from approximately 350 to 550 feet. The elevations of the gaps vary from 940 to 1180 feet A. T., a difference of 240 feet. The average breadth across the top is from one-half to three-quarters of a mile, and at the bottom a few hundred feet. Seen from the north, they all appear to be broadly rounded sags, the sides of which merge by continuously convex slopes of low angle into the ridge crest. Their sides have an average maximum angle of about 12° and are covered by accumulations of debris, the product of weathering in place and movement down slope. No facets appear in their profiles, all being of smooth contour, a condition which is to be expected where the sides are graded and such a high angle of dip occurs that structural facets are not produced. The slope of the ridge crest is everywhere toward the gaps and varies from 1° to 6°.

The original steep sides of the notches have been much modified by weathering and the accumulation of debris since the abandonment of the streams which once occupied them. The slope of the ridge crest toward the gaps is significant, indicating superposition of the streams across Berry Mountain during an earlier cycle than the Schooley (Kittatinny). Variable elevations such as occur in this series of wind gaps, all so close

FIG. 44.—Wind Gap in Berry Mountain located one mile and one-quarter from the Susquehanna River. View from the north.

FIG. 45.—Profile of the wind gap appearing in the photograph above, showing angles of slope.

FIG. 46.—Wind Gap in Berry Mountain located two and three quarters miles from the Susquehanna River.

FIG. 47.—Profile of the wind gap in Berry Mountain two and three quarters miles from the Susquehanna River, showing angles of slope. As seen from a point to the north.

FIG. 48.—Wind gap in Berry Mountain located five miles east of the Susquehanna River. View from the north.

to one another, indicate that there is little evidence here in support of the theory that wind gap elevations are accordant and mark fluvial base levels.

Obviously the streams which cut the Berry Mountain group of wind gaps had their headwaters on Broad Mountain and flowed northward toward the Susquehanna River. Armstrong Creek, south of Berry Mountain, was probably the stream which accomplished the piracy. It is impossible to determine the exact courses of the streams which flowed through the wind gaps. They may have been tributaries to Wisconisco Creek, or they might have extended over Mahantango Mountain. It is entirely possible that Deibler's Gap in Mahantango Mountain was occupied by a stream which headed on Broad Mountain and flowed through one of the wind gaps in Berry Mountain. If some of the streams which headed on Berry Mountain flowed northward over Mahantango Mountain, Wiconisco and Mahantango creeks may have aided in the piracy which converted the transverse drainage across the ridges to longitudinal, subsequent drainage, parallel to the ridges.

After a study of the drainage lines of the present and the past, there can be no doubt that the Broad Mountain area between the two narrow synclines which has the structure of an anticline was a broad, low swell or monadnock upon the Schooley (Kittatinny) peneplane. The axis of this low arch was a divide between the north- and south-flowing streams; its greatest elevation was several hundred feet above the level of the valleys to the north and south. It sloped toward the Susquehanna on the west

FIG. 49.—Profile of the wind gap appearing in the photograph above, showing angles of slope. As seen from a point to the north.

FIG 50 —Wind gap in Berry Mountain located southwest of Elizabethville As seen from a point to the north

and flattened out to the east, where it merged into the general level of the peneplane. This anticline or monadnock, capped with the hard, resistant Pocono sandstone, stood so high above the general level of the valleys cut on the softer shales that it determined the direction of the drainage lines. It may be that the great bend in the Susquehanna River was determined at a time prior to the Schooley (Kittatinny) cycle by the presence of this broad arch. Just what the conditions were when the Susque-

FIG. 51 —Profile of the wind gap near Elizabethville, showing angles of slope. From a point directly in line and to the north.

hanna acquired its course across the apices of the synclines it is difficult to determine. The evidence seems to favor the theory that the Susquehanna River had already acquired its present course across the ridges prior to the completion of the Schooley (Kittatinny) peneplane and at a time before the Schooley (Kittatinny) cycle. In other words, the Broad Mountain monadnock on the Schooley (Kittatinny) peneplane is sig-

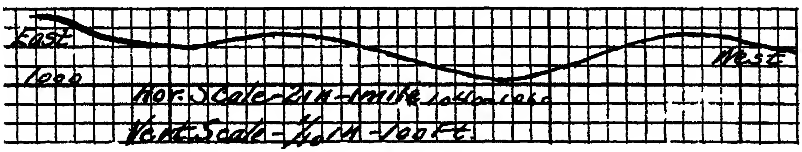

FIG. 52 —Profile of the wind gap near Elizabethville, taken from the topographic map.

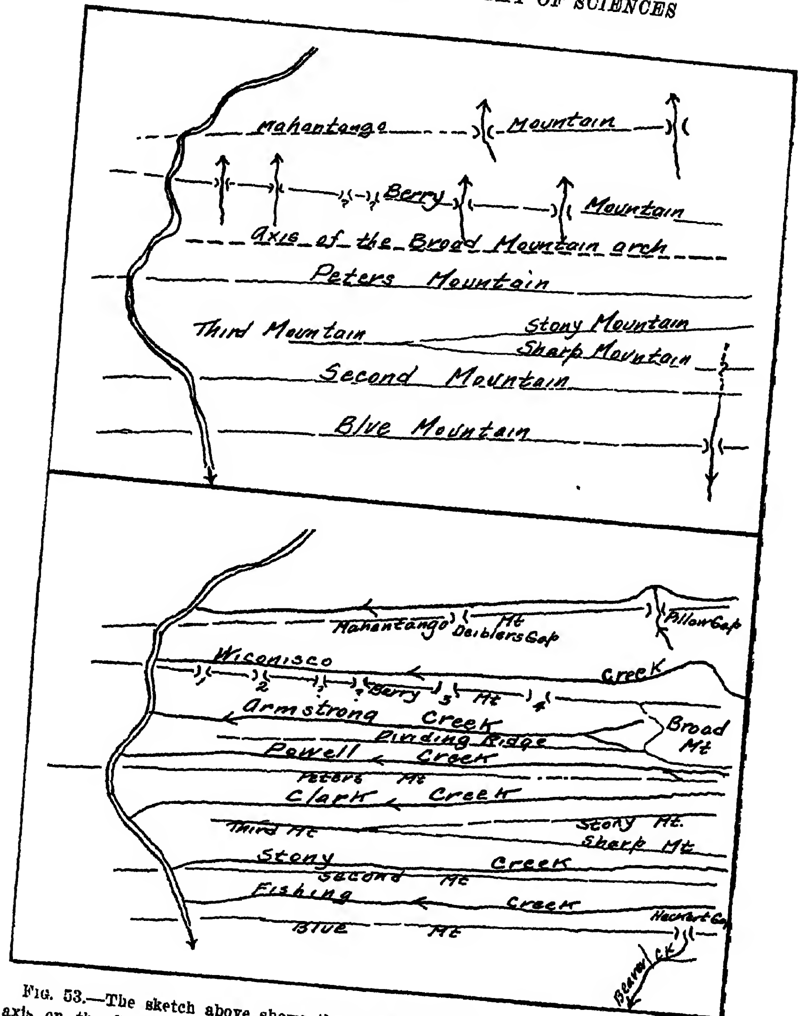

FIG. 53.—The sketch above shows the probable drainage from the Bread Mountain axis on the Schooley (Kittatinny) peneplane. The lower sketch shows the present drainage. The wind gaps in Berry Mountain are numbered in order of distance from the Susquehanna River.

nificant because it indicates, like the slopes on the ridge crests on which the ancient divides are preserved, that the streams were superposed in a cycle earlier than the Schooley (Kittatinny) and held their courses throughout Schooley (Kittatinny) time. The pronounced slope of the

FIG. 54.—Deibler's Gap in Mahantango Mountain. View from the south

ridge crests toward the gaps everywhere in the Appalachians of eastern Pennsylvania seems to be conclusive evidence that the rolling Schooley (Kittatinny) peneplane was developed by the Delaware, Lehigh, Schuylkill and Susquehanna rivers and their tributaries during the Schooley (Kittatinny) cycle.

FIG. 55.—Profile of Deibler's Gap from the south, showing angles of slopes.

Deibler's Wind Gap

Mahantango Mountain is cut by an excellent wind gap, at a point about midway between the Susquehanna River and the water gap at the town of Pillow (Fig. 54).

The Pocono sandstone of which Mahantango Mountain is composed dips approximately 50° to the south and constitutes the north limb of a syncline.

Deibler's Gap is about 340 feet deep, the distance below the Schooley (Kittatinny) peneplane. The elevation of its bottom is 900 to 920 feet A. T., which is about 200 to 250 feet above the Harrisburg peneplane to

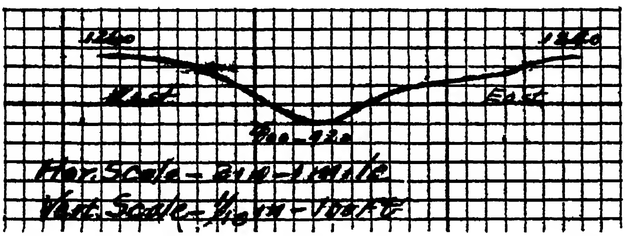

FIG 56.—Profile of Deibler's gap, showing elevations. Taken from the topographic map.

the south. Across the top the notch is approximately one-half to two-thirds of a mile wide, and at the bottom several hundred feet at least.

From the south Deibler's Gap presents a very symmetrical profile and is an excellent example of a typical wind gap. The outline is broadly rounded and the sides are convex with maximum angles of about 10°, grading by a continuously convex slope into the ridge crest. A feature characteristic of wind gaps and especially well marked in this instance is the broadly rounded, low angle at the contact of the sides and the ridge crest (Fig. 55).

No facets occur in the profile of the notch; its slopes are well graded and no angularities due to rock ledges appear. Obviously, since the abandonment of the notch by the stream which once flowed through it, much debris has collected, modifying the original V-shape of the water gap.

The ridge crest slopes at low angles toward the notch; on the east the highest point is 1280 feet A. T., and is located about one and one-half miles to the west of the Pillow Water Gap. This point marks a divide between two streams on the Schooley (Kittatinny) peneplane. On the west the ridge crest is highest at a point about midway between the Susquehanna River and the gap. Here the elevation is 1300 feet A. T. and indicates another divide on the Schooley (Kittatinny) surface.

What drainage changes have occurred at Deibler's Gap cannot be stated with assurance, for different interpretations are possible. One might venture the theory that the stream extended through one of the wind gaps in Berry Mountain, all of which have elevations above Deibler's Gap. The stream flowed northward and may have had its source on the Broad Mountain arch, the wide, low monadnock which served as the divide between the streams flowing across Blue Mountain toward the Great Valley on the south, and those flowing across Berry and Mahantango mountains to the north (Figs. 57 and 58). The theory that the stream which occupied Deibler's Gap flowed north is supported by the fact that the streams of the Pillow and Klingerstown water gaps also flowed in that direction. The stream which flowed through Deibler's Gap was possibly a tributary to Mahantango Creek, and Little Wiconisco Creek may have accomplished the piracy. We cannot be certain as to what the drainage history has been, except that the subsequent streams have been the pirates which beheaded those crossing the ridges. The capture which produced Deibler's Gap and the notches in Berry Mountain took place during the Harrisburg cycle, because there appears to be no evidence for

more than two peneplanes,—the Schooley (Kittatinny) on the ridge crests and the lower one, which is well developed on the Mauch Chunk shales in the broad valley between Mahantango and Berry mountains.

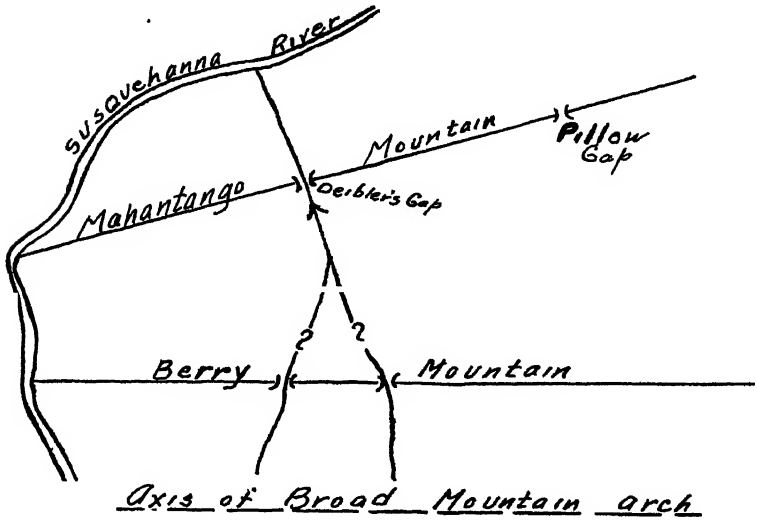

FIG. 57.—Possible course of the stream which occupied Deibler's Gap.

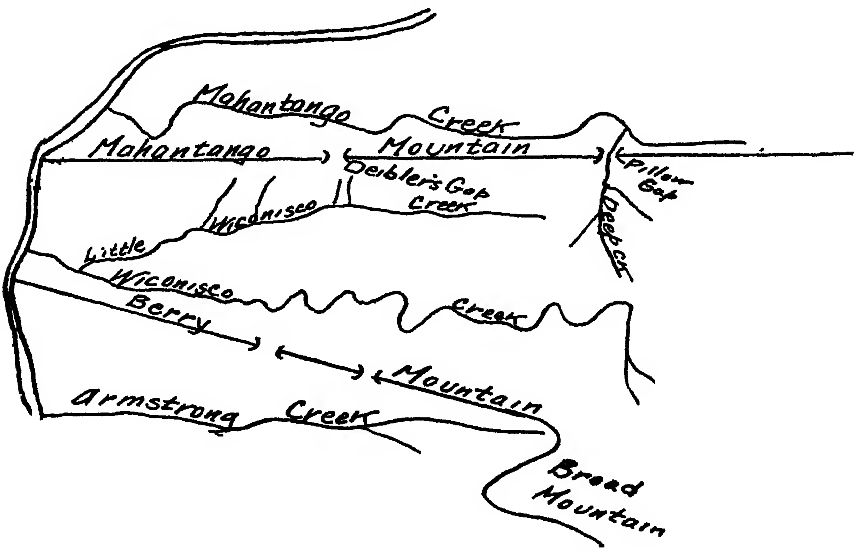

FIG. 58.—Present arrangement of the drainage lines after piracy has taken place.

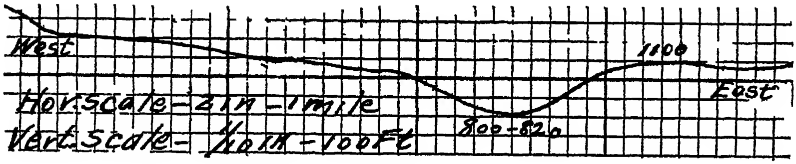

FIG 59—Profile of Mitchell Gap, taken from the topographic map

MITCHELL WIND GAP

An interesting notch called Mitchell Gap is present in the ridge known as Buffalo Mountain, at a point about eight miles west of the Susquehanna River Here Berry and Buffalo mountains meet to form a sharp curve or cove, which in shape resembles the prow of a canoe (Fig 60) The structure is that of a syncline, the axis of which pitches in a northeasterly direction. The ridges are composed of the Pocono sandstone, the dip of which is about 50° to 60° toward the axis of the structure

The depth of Mitchell Gap is approximately 300 feet, which is the distance below the Schooley (Kittatinny) peneplane Its elevation is 800 to 820 feet A. T and the height above the Harrisburg peneplane at least 100 feet. The width of the notch across the top is one-half of a mile and at the bottom several hundred feet.

The form of the gap is that of a symmetrical, broad, open sag, with gently rounded floor, typical of nearly all the wind gaps in the Appalach-

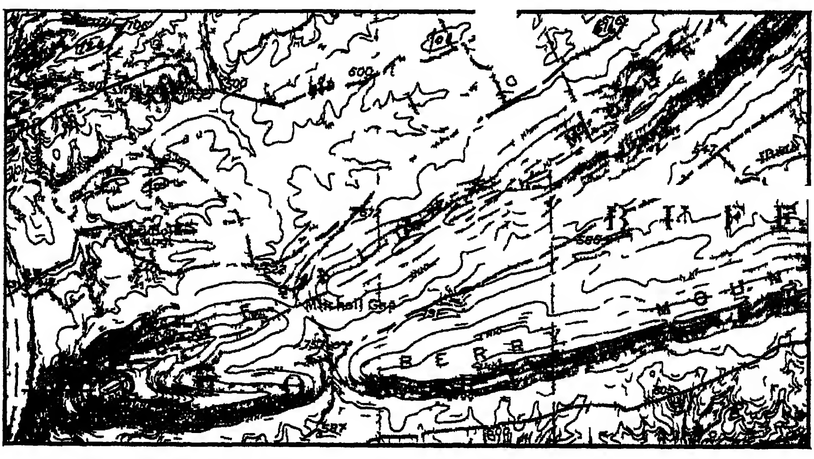

FIG 60—Section of the Millerstown Quadrangle showing Mitchell Gap and the surrounding region

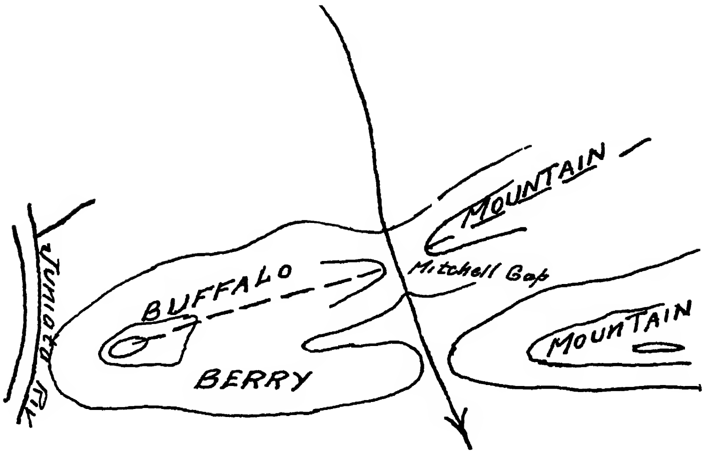

FIG 61 —Possible drainage prior to the piracy which produced Mitchell Gap

ians The sides are of low angle, the maximum being 15° to 20° at the base, grading by continuously convex slopes into the ridge crest (Fig 59)

The sides and bottom are covered with debris giving the notch the rounded profile so characteristic of wind gaps The gently rounded curve into the ridge crest is due, as explained elsewhere, to the weathering back of the sides, since the stream abandoned its course through the notch In Mitchell Gap the grade slopes are nearly smooth with no pronounced

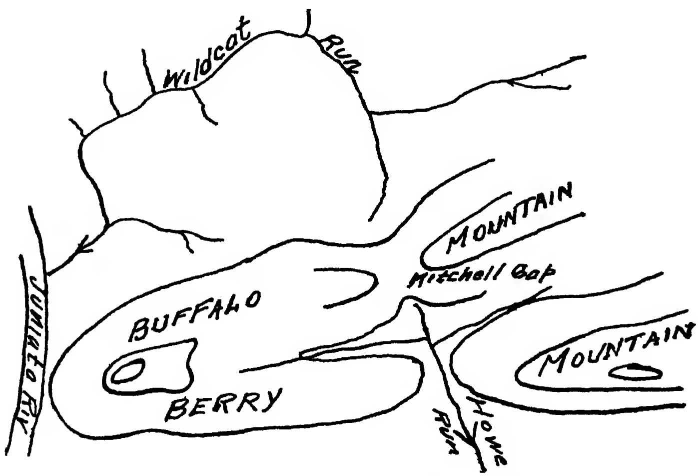

FIG 62 —Present drainage after the piracy which produced Mitchell Gap

angularities or facets. This is accounted for by the high angle of dip of the beds and the thick accumulations of debris on the sides and bottom.

The ridge crest on both sides slopes at a very low angle toward the gap. On the west the slope is from the apex of the syncline, located about a mile and one-half from the notch. At this point, where the two mountains meet, the altitude is about 200 feet higher. This is due to the fact that at the apex of the syncline there may be greater thickness or broader exposure of the Pocono sandstone. At that point there probably existed a low, rounded knoll or monadnock on the Schooley (Kittatinny) peneplane. Many similar elevations occur in the Appalachians where the same conditions prevail. Hence streams could not cross the ridges at the apices of the structures but were forced to cross at the lower points on the sides. The streams of the Appalachians never enter an anticlinal or synclinal structure by crossing the apex but cross the ridges on either side of it.

It is probable that the creek which cut the water gap through Berry Mountain to the south once extended northward through Mitchell Gap (Fig. 61). It is exceedingly difficult to explain the course of the stream across two hard sandstone ridges, so near the apex of the syncline, unless we assume that it was superposed on a coastal plain which once extended inland over a large part of the Appalachians.

Wild Cat Run, north of Buffalo Mountain and a tributary of the Juniata, gradually robbed Mitchell Gap Creek of its headwaters, causing the abandonment of its valley across the ridge. The lower portion of the stream, called Howe Run, and a tributary to the Juniata River, still occupies the gap in Berry Mountain (Fig. 62).

THE WATER GAPS

Delaware Water Gap

The gap cut by Delaware River through Kittatinny Mountain is one of the finest examples of a water gap in the Appalachians. It is unusually striking because of its great depth and narrowness and the steepness of its cliffs, a combination not possessed by any other gap in eastern Pennsylvania.

Delaware Water Gap is a gorge 1200 feet deep, approximately three-fifths of a mile wide at the bottom and about one mile wide across the top, and stands 280 to 300 feet A. T. It has been cut by the Delaware River, which once flowed across the upper edge of a layer of harder rock, the Shawangunk conglomerate, when it was part of a general lowland surface

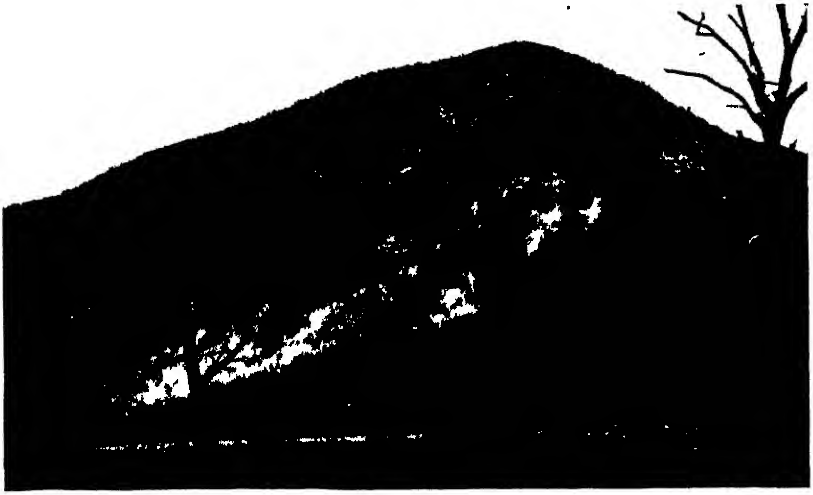

FIG 63.—East wall of the Delaware Water Gap, showing the Oneida conglomerate and talus slope below it.

near sea level. On this surface, the Schooley (Kittatinny) peneplane, flowed the Delaware, Lehigh, Schuylkill and Susquehanna rivers and a host of tributaries and smaller streams. These were superposed on the ridges at a time probably earlier than the Schooley (Kittatinny) cycle. As the land rose, the Delaware River cut its gorge deeper and deeper. The softer rocks on either side were stripped away and the hard conglomerate of Blue Mountain was left standing with the great V-shaped cleft cut through it.

FIG. 64.—Delaware Water Gap as seen from the south. Photograph taken from the concrete bridge about one mile north of Portland.

By reference to the map it will be seen that the crest of the mountain on the New Jersey side of the river is not in line with the crest on the Pennsylvania side, but lies about 700 feet farther north. The New Jersey mountain is about 100 feet higher than the Pennsylvania side, being 1187 feet above river level, while the highest point reached upon the New Jersey side is 1291 feet above the same datum level. The back throw of the mountain is occasioned by the difference of the dip upon the two sides of the river. Upon the New Jersey side the strike of the beds is North 60°, 20′ East, whereas upon the Pennsylvania side it is North 70°, 10′ East. These facts point to warping of the formations rather than to a fault for the origin of the difference of dip.

The following discussion on the structure of the ridge is based on the work done by the Pennsylvania Geological Survey and the names of the various rock subdivisions are the old ones. The formations which concern us most are those resistant ones which form Kittatinny Ridge and which outcrop in the gap (Fig. 66). The Hudson River slates or the Martinsburg shales, as they are now called, constitute the lowest formation, which outcrops in the notch and dips about 15° North 20° West. Resting on the Martinsburg slates are the Oneida strata, consisting of hard, massive white conglomerate, with some beds of hard, gray sandstone in the upper part of the mass. They form a bold line of cliffs, sometimes 200 feet high on the southern flank of the mountain. It constitutes the lower ledge so conspicuous in Delaware Gap and marks the first and lowest facet in the gap. Below this ledge occurs the talus slope which covers the Martinsburg slates (Fig. 71). Upon the Oneida conglomerate lies a mass of gray sandstone having a thickness of 240 feet. This is much softer than the beds between which it lies and is covered by the debris from them, rendering an accurate description impossible. The position of this formation, which constitutes facet 2 in the profile of the gap, is marked by gentler slopes and absence of cliffs. A strip of forest consisting mainly of pine trees marks its position.

A hard, compact, white sandstone with some beds of conglomerate lies above the Oneida gray sandstone and forms a marked bench just south of the crest of the mountain, and it is also seen in the gap, forming a thin rib running up parallel to the main escarpment. The sandstone produces a slight, rounded angularity in the profile of the gap; it is too thin to give a good facet, but marks the division point between facets 2 and 3.

The Medina Lower Olive shales are composed of soft, grayish sandstones with some beds of shale. This formation seems to have nearly the

same character as the mass lying between the Oneida conglomerate and the Oneida gray sandstone. It is nearly everywhere covered by a thin layer of earth and debris of loose stone. It produces facet 3 in the profile of the gap.

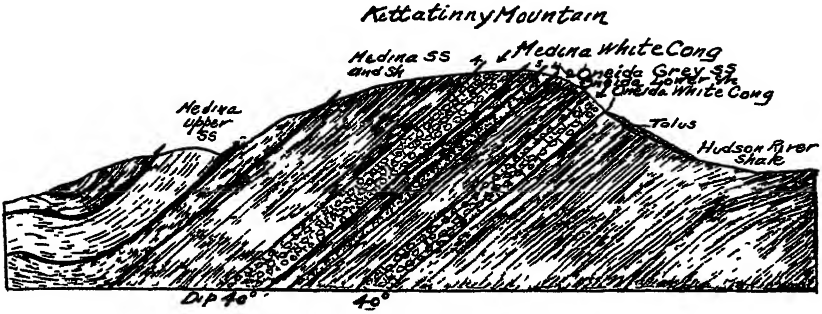

Fig. 65.—Structure section of the east side of the Delaware Water Gap. (Penn. Survey.)

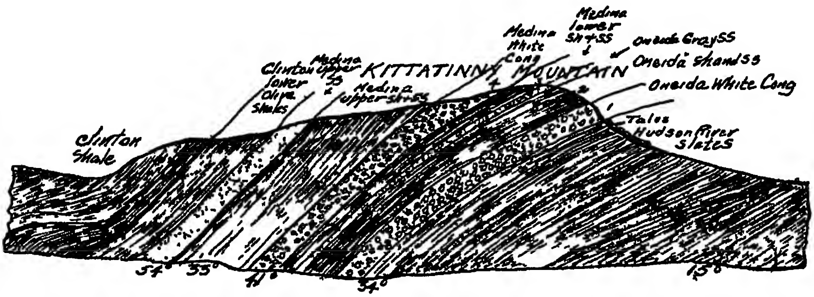

Fig. 66.—Structure section of the west side of the Delaware Water Gap. (Penn. Survey.)

Fig. 67.—Profile of the Delaware Water Gap, showing elevations. Taken from the topographic map. Numbers indicate approximately the location of the facets.

The Medina white conglomerate next above is a hard, compact, pea conglomerate with beds of hard, coarse and fine-grained, gray sandstone. On the New Jersey side of the gap this rock formation, 200 feet thick, forms a line of cliffs which from a distance appear to be rounded. On the Pennsylvania side of the river its outcrop is passed over just before reaching the crest of the ridge. The long, gentle slopes of the ridge crests toward the gap constitute facet 4 and occur on the Medina white conglomerate. This facet bevels the structure and represents the old valley on the Schooley (Kittatinny) peneplane, below which the gap was cut.

The Medina Upper Olive shales and the Medina Upper sandstone, which lie successively above the Medina white conglomerate, have a total thickness of about 730 feet and do not in any way affect the profile of the gap.

The three hard rock formations, which are responsible for angularities in the convex profile of Delaware Gap, are the Oneida white conglomerate, which constitutes the lower ledge, the thinner bed called the Oneida gray sandstone, which makes a slight angularity in the profile of the gap, and the thick, resistant bed of Medina white conglomerate, which composes the upper ledge and forms the ridge crest on both sides of the river. The formations between, being softer and less resistant, weather down and are marked by gentler slopes. The alternating series of resistant quartz conglomerate and weaker sandstone and shales produce what have been called facets in the profile of the gap. The writer believes that, if there were any facets produced by widening of the gaps during periods of halt or still-stands of the land in the course of the general uplift of the Appalachians, they have been obscured by the development of structural facets. Viewed from the south, two miles north of the town of Delaware, the east side of the gap shows four distinct facets (Fig. 70). Three of these are obviously related to hard rock ledges, whereas the ridge crest represented by facet 4, which slopes gently toward the gap, is an old erosion surface. From the valley to the south the upland surface appears to be nearly level and the sloping ridge crest seems to grade imperceptibly into the upland. Looking north from the town of Slateford, which is located south of the gap, a study of the east side shows clearly that facets 2 and 3 are related to hard ledge makers.

Barrell (*1*) says very little about the Delaware Water Gap but remarks on page 340, "The cliffs of the Delaware Water Gap are well known." He does not refer to any facets in its profile. Facet 3 occurs at the level which Barrell correlated with a higher system of wind gaps at 1350 feet A. T. and which he considered marked the Schooley baselevel. This

FIG. 68.—Delaware Water Gap from the railroad bridge at Portland. View from the south.

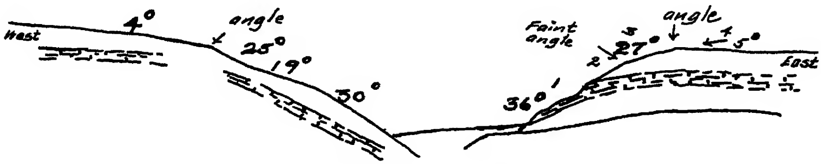

FIG. 69.—Profile of the Delaware Water Gap, taken from the photograph above. Angles measured in the field at the same point from which the photograph was taken.

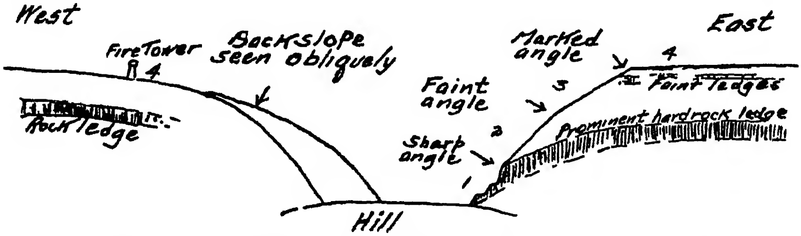

FIG. 70.—Sketch of the profile of Delaware Water Gap from a point not far from the town of Delaware. Angles of slope are numbered.

facet is much too steep and sharply contrasted with the upland to represent part of a valley on a former peneplane. The present writer is of the opinion that all the facets except number 4, which represents the old valley on the Schooley (Kittatinny) peneplane, are structural and therefore do not mark fluvial baselevels.

Looking east toward Tammany, from the top of the west side of Delaware Gap, three facets are clearly visible in the cross profile of Kittatinny Mountain (Fig. 72). These appear on the southeast side which faces the Great Valley. No facets are found on the northwest side of Blue Mountain; but this is not to be wondered at, for facets would not be so apt to occur on the dip slope, while cliffs and prominent angles in the profiles would be expected on the side where the rock formations are truncated. The absence of facets on the north side of Blue Mountain and their presence on the south side indicate that the hard rock ledges are the cause of their

FIG. 71.—East wall of the Delaware Water Gap, showing the upper and lower conglomerate beds. The Harrisburg peneplane is seen sloping from the Blue Mountain.

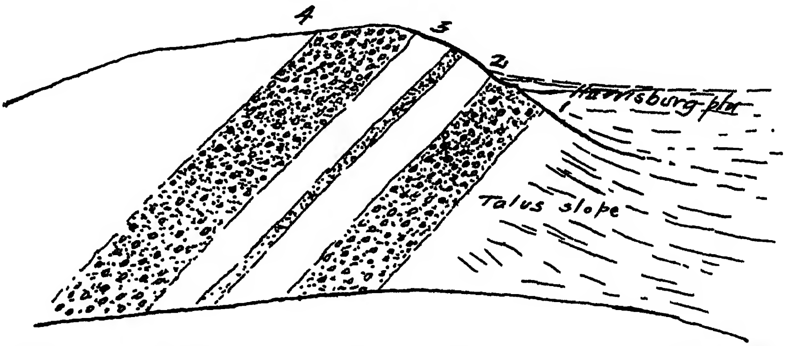

FIG. 72.—Cross-profile of Blue Mountain at the Delaware Water Gap, showing angles of slope and relation of slope to the hard rock beds.

existence. Furthermore, the same facets which appear on the south side of Kittatinny Mountain occur also in Delaware Water Gap. The profile of the gap (Fig. 67) does not show the facets so clearly as one observes them in the field because slight details in the profile of a gap are not likely to appear on a topographic map.

One peculiar feature of the Delaware Water Gap is the long, gentle slope (Fig. 67) of the ridge crest on the west side from a point west of the fire tower downward toward Tott's Gap. This is abnormal, for the slope of the ridge crest should be a long one downward toward Delaware Water Gap, which is the larger notch. The Tott's area is more irregular and seems distinctly below the Schooley (Kittatinny) peneplane level, as shown on the crest of the ridge farther west. As seen from the fire

tower near the Delaware Water Gap, the ridge crest slopes upward to the west, to a point about a mile beyond the fire tower, and then slopes gently downward toward Tott's Gap. If one looks from the same point, the top of the ridge crest on the west side of the Delaware Water Gap is seen to be very broad at the tower but narrows markedly to the west. This may be due to structural reasons, which may thus account for the lower elevations toward Tott's Gap. If the profile (Fig. 1) is examined, it is quite obvious that there is a faint general slope of the ridge crest from the Little Offset (1600 feet A. T.) toward the Delaware Water Gap, where the elevation reaches 1480 feet A. T. at the fire tower. This slope is broken by Fox Gap and Tott's Gap, now shallow wind gaps but once occupied by tributaries belonging to the Delaware drainage system on the Schooley (Kittatinny) peneplane.

The sides of Delaware Gap at a distance do not appear to be so steep as at close range. The angles of slope were measured from a point about three miles south, from the bridge at Portland, Pennsylvania (Fig. 69). The west side has a maximum slope of 30° in the lower part of the gap, decreasing to only 4° on the ridge crest. The east side is somewhat steeper, for the lower part has a slope 36° which decreases to an angle of but 5°. Although the ridge crest on the east side appears to be level, a definite slope toward the gap exists. The river makes a curve in its course through the notch and therefore the east side on the outside of the bend, which is the undercut slope, is the steeper. The average slope for both sides is about 30°.

A study of the ridge crests at the Delaware Water Gap did not give conclusive evidence indicating glaciation. A water-worn cobble stone was found on the west side of the gap not far below the top of the ridge. This may have been carried upward by the ice. All evidence such as glacial grooves, striæ, chattermarks, erratics and marked smoothing and polishing by the ice are lacking on the ridge crest. If glaciation did occur there, it has left little, if any, traces. In the Delaware Water Gap, smoothed rock surfaces and glacial striations reveal the former presence of ice.

Lehigh Water Gap

Where Lehigh River crosses Blue Mountain, it has cut a gap, the symmetry, depth and narrowness of which is very striking, especially when seen from the Great Valley to the south (Fig. 73).

The elevation of the floor of Lehigh Gap is 393 feet A. T., about 1000 feet below the ridge crest, the elevation of which is approximately 1400

FIG. 73.—Lehigh Water Gap from the south.

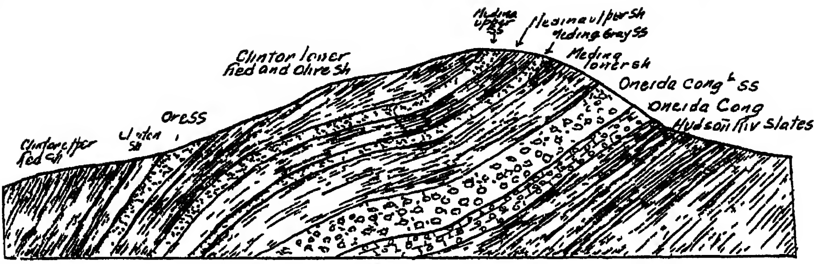

FIG 74—Structure section of Blue Mountain at the Lehigh Water Gap. (Penn. Survey.)

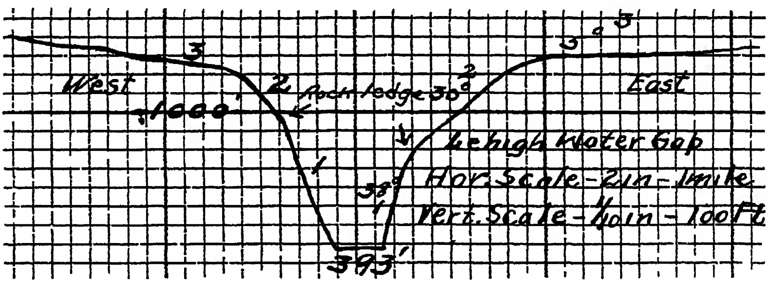

FIG. 75.—Profile of the Lehigh Water Gap, showing elevations. Taken from the topographic map.

feet A. T. It is the deepest notch in the Northern Appalachians, with the exception of the Delaware Gap, the depth of which is 1200 feet. The breadth of the gap across the top is about four-fifths of a mile and its floor about one-eighth of a mile, indicating that the notch is a very narrow one when compared with the majority of those in the region.

In the center of the gap exposures reveal a gentle anticline, which becomes sharper to the east and forms a hook in the mountain crest at a point about a mile east of the notch. In the immediate vicinity of Lehigh Gap, the flexures are gentle and the resulting topography shows no extraordinary features. South of the mountain the topography consists of a monotonous succession of slate hills. A valley 1500 to 2000 feet wide lies north of the mountain presenting no exposures of the underlying rock. This valley separates the mountain from a rather sharp, dissected ridge (Stony Ridge), formed by the outcrop of the Oriskany sandstone. A very interesting topographical feature presents itself where Aquashicola Creek flows in an easterly direction along the north foot of the mountain, and empties into the river at the head of the gap. At the junction of the Aquashicola with the Lehigh, is a beautifully rounded hill (Fig. 76) composed mainly of Clinton red shale and isolated from the mountain by two streams. Prior to the glacial period the Aquashicola emptied into Lehigh River north of this hill. From the foot of the hill to the southern flank of Stony Ridge, the old valley is filled to a height of 80 feet by a sort of moraine. This formation obstructs the ancient watercourse of the Aquashicola and, acting as a barrier, has forced the creek to erode the new channel through which it now flows.

The structure and the rock formations which make up Blue Mountain at the water gap are discussed by H. M. Chance in a paper entitled "Special Survey of the Lehigh Water Gap," contained in the Report of Progress G 6, Second Geological Survey of Pennsylvania, 1881. The lowest formation outcropping in the gap is the Martinsburg slate. The upper portion of the mass is well exposed, immediately underlying the Oneida conglomerate. Above the slates the resistant conglomerate forms a cliff which extends up the mountain on the east side of Lehigh Water Gap and is exposed along the railroad, at which point the dip is from 24° to 31° North, 20° West. This formation, which forms a steep declivity on the southern side of the mountain, is composed of three beds of conglomerate and one of hard sandstone.

The Oneida conglomerate sandstone, a massive, white and light grey conglomeratic sandstone, 290 feet thick, lies above the Oneida conglomerate and is exposed in a long cut along the L and S railroad, where the anticline is visible. It outcrops south of the mountain crest and forms the top of the high cliffs seen at the "Devil's Bake Oven" a few miles west of the gap.

The next formation above is the Medina lower shale, consisting of rather soft brownish shales with a few sandy beds. Immediately above

the middle of the mass there is exposed a white, conglomeratic sandstone, from 25 to 30 feet thick. The shales, about 330 feet thick, occupy the crest and southern slope of the mountain above the outcrop of the Oneida.

The Medina white sandstone, consisting of an alternating series of sandstones, lies next above. The outcrop forms the mountain crest and is about 70 feet thick.

The Medina upper shales, about 180 feet thick, outcrop on the mountain side just north of the crest. The Medina upper sandstone, about 85 feet thick, lies next above. The dip of the formation is about 42° to 58° North, 5° West; it presents several bold outcrops in the gap, of which the "Devil's Pulpit," is the most prominent.

The Clinton red shale, about 290 feet in thickness, comes next. The upper part of the mass is well exposed above the railroad station in the gap. These shales form the terrace on the north side of the mountain.

The crest of Blue Mountain presents a regular, rounded contour. Cliffs formed by the hard beds of sandstone and conglomerate, appearing near the base of the Silurian series, are much less prominent than those of the Delaware Gap. Consequently the facets, so pronounced in the profile of the Delaware Gap, are fainter and the sides present an almost uniformly smooth surface.

Viewed from the south, the profile of Lehigh Gap appears quite smooth, no sharp angles occurring to break the uniformly convex slopes. Nevertheless, there are changes of slope due to rock ledges, either visible or concealed, which appear as slight irregularities, producing structural facets. These are apparent when one sights along a straight edge. On the west side there are four slopes which may be interpreted as facets. The lowest one is marked by a very conspicuous ledge or cliff of rock which juts into Lehigh Gap. This ledge shows up clearly in the photographs taken from the north (Fig. 76). Above this ledge, which has a nearly flat top, the slope at first is gentle, becoming steeper above. A distinct change in slope then occurs, but the change is gradual and the angle, which is rounded, is very faint. This variation is due to a ledge of more resistant rock. Another change in slope takes place where the gap merges gradually by a continuously convex profile into the crest of the ridge, which is gently inclined toward the gap on both sides of the river. The upper slopes on the ridge crest constitute the sides of the old Lehigh Valley on the Schooley (Kittatinny) peneplane, below which Lehigh Gap is cut.

On the east side as seen from the south, only one slight irregularity occurs in the otherwise uniformly convex profile and this is clearly due

FIG. 76.—Lehigh Water Gap as seen from the north. Note the prominent ledge on the west side.

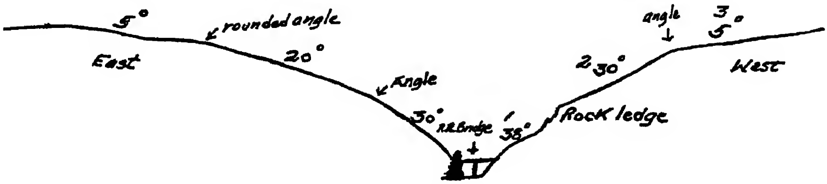

FIG. 77.—Profile of Lehigh Water Gap from the ridge to the north of Palmerton. From a point at a slight angle to the gap. The observer is directly in line with the west side. The facets are numbered.

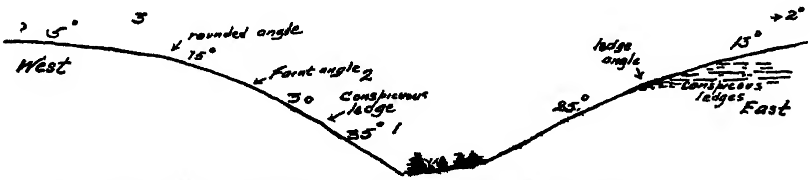

FIG. 78.—Profile of the Lehigh Water Gap, showing angles of slope. From the south and from a point directly in line.

to a prominent rock ledge. This side likewise merges by a continuously convex slope into the crest of the ridge. The facets in this gap are obviously the result of hard rock ledges and cannot have any relation to different cycles of erosion. They are so very faint in any case that they are of doubtful value as criteria of cycles of erosion.

Viewed from the north, the profile of Lehigh Gap presents at least three distinct facets on the west side. The lower facet ends at the top of the prominent rock ledge called the "Devil's Pulpit," which shows clearly in the photograph (Fig. 76). This ledge produces a facet at a higher level farther south, up the dip of the formation, proving that these facets are related to rock resistance rather than to cycles of erosion. One

would expect the facet above the "Devil's Pulpit" to be more gentle, because the Lehigh River was checked longer on the hard rock layer than at any other part of the gorge and the weak beds above have weathered to gentle slopes. The hard rock ledge holds up the softer, weaker beds beneath. From the north the profile of the east side of Lehigh Gap presents a nearly uniformly smooth, convex slope. Two faint angles appear, which in the field are seen to be clearly the result of hard rock ledges that form prominent outcrops.

The degree of slope of the sides of the gap vary when viewed from different angles. On the west side, as seen from the south and directly in line with the gap (Fig. 78), the steeper, lower portion beneath the ledge has a slope of 35°, decreasing upward to 30°, then 15° and finally to 5° on the ridge crest. The eastern side has a more gentle slope, being about 25° in the lower portion, 13° above the ledge and finally 2° on the ridge crest. When the gap is observed at an angle from the ridge north of Palmerton at the sand quarry, the sides appear to be somewhat steeper, as the angles show (Fig. 77).

Barrell (*1*), in speaking of the Lehigh Gap, remarks (pp. 338-342), "The Lehigh Gap below the level of the wind gaps shows two facets, an upper at about the angle of repose, a lower marked by a rock cliff." Barrell recognizes an upper set of wind gaps at about 1350 feet A. T., which he correlates with upper, older valleys belonging to a second cycle of erosion, the Schooley. It is obvious from the statement cited that he does not recognize at the Lehigh Gap an older valley above the 1350 feet A. T. level. This valley is clearly represented by the gentle slopes of about 2° to 5° on the ridge crest slanting downward toward the gap. These slopes correspond with those occurring on the ridges at almost all the gaps in eastern Pennsylvania. They mark the Schooley (Kittatinny) peneplane, which the present writer regards as the highest surface in the Northern Appalachians, and are significant because they indicate that the Lehigh River was superposed in a cycle earlier than the Schooley (Kittatinny) and held its course throughout Schooley (Kittatinny) time.

The accompanying photographs and profiles of Lehigh Gap show below the 1350 feet A. T. level two distinct facets. These are, according to the present writer's interpretation, structural facets due to alternating layers of hard and soft rock. Furthermore, the comparatively low angle of dip of the formations is favorable to their development. The angles are shown in Fig. 76 and are due to outcropping ledges of resistant sandstone. Barrell's upper valley is represented by facet 2 in Fig. 77 and the lower facet mentioned by him is represented in Fig. 77 by number 1.

The prominent rock cliff alluded to by Barrell is the one which occurs on the west side of the gap, at an altitude of about 800 feet and is locally known as the "Devil's Pulpit." The older, higher valley located above 1350 feet A. T. and not recognized by Barrell is designated as facet number 3 in Fig. 77.

The Harrisburg peneplane shows up to good advantage along the Blue Mountain front at Lehigh Gap. The peneplane abuts against Blue Mountain and slopes off to the south, merging into the undoubted Harrisburg surface of the Great Valley. There is also a pronounced slope of the Harrisburg peneplane toward the Lehigh River. There seems to be no evidence of a peneplane between the Schooley (Kittatinny) surface and the sloping Harrisburg peneplane below. The writer is convinced that the facets in the gap have no relation to cycles of erosion, except for the broad valley indicated by the gentle slopes on the ridge crest, which represents the Schooley (Kittatinny) surface. Although there may have been short halts in the general process of uplift of the land, widening of the gaps due to peneplanation did not take place. The evidence is in favor of continuous uplift with halts so short that they did not produce peneplanes.

A careful but unsuccessful search was made for water-worn gravels on the ridge crest east of Lehigh Gap. Here the Schooley (Kittatinny) peneplane is well represented by the undulating surface between Little Gap and Lehigh Gap. The ancient surface is well preserved and illustrates the gently rolling character of the Schooley (Kittatinny) peneplane.

The Water Gaps at Tamaqua

Little Schuylkill River cuts through three ridges north and south of the town of Tamaqua. The Philadelphia and Reading Railroad and a state highway pass through the gaps, connecting Tamaqua with the Great Valley and the towns along the Schuylkill River to the south.

The notches vary in width from less than one-half to three-quarters of a mile across the top, and their floors also vary from about 250 feet for the narrowest to 650 feet for the broadest. The depth does not exceed 650 feet nor is it less than 500 feet.

Tamaqua is located on the coal measures and the rock formations have the structure of a syncline. This syncline extends northeastward from Pottsville and is a continuation of the Pottsville coal basin. The two ridges, Locust Mountain and Sharp Mountain, are composed of the hard,

FIG. 79.—View of the gaps in Second and Sharp mountains as seen from Locust Mountain; Tamaqua in the foreground.

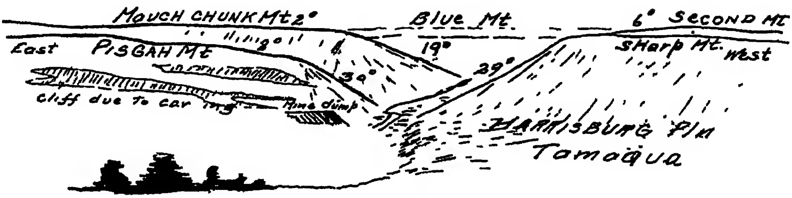

FIG. 80.—Sketch of the gaps in Second and Sharp mountains as seen from a slight angle. Profile taken from the photograph above. Angles of slope about the same when seen from a point in line.

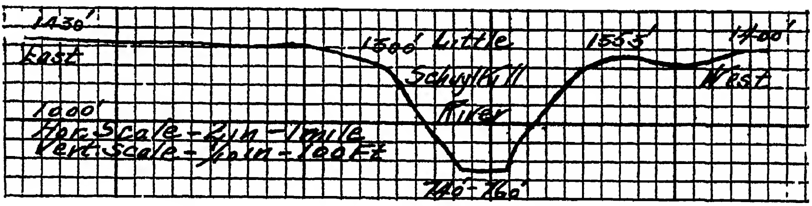

FIG. 81.—Profile of the gap in Sharp and Pisgah mountains. Taken from the topographic map.

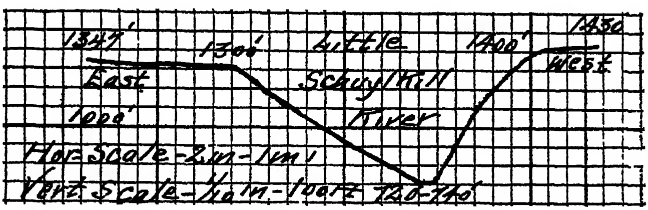

FIG. 82.—Profile of the gap in Second and Mauch Chunk mountains. Taken from the topographic map.

resistant Pottsville conglomerate. This formation has a dip of about 55° to the southeast at Locust Mountain, and in the gap at Sharp Mountain the conglomerate dips north about 50°. The north half of Second Mountain or Mauch Chunk Mountain, as it is called, east of Little Schuylkill River, is composed of the Pocono sandstone, which dips north at an angle of about 50°. The south half is made up of the upper part of the Catskill formation.

The photograph of the gaps in Second and Sharp mountains was taken from "Table Rock," a projecting ledge of the Pottsville conglomerate on Locust Mountain. The west side of the gap in Second Mountain is not visible from this point, but enough can be seen to give the observer valuable information concerning the presence of facets, the angle of slope of the sides and the shape of the gaps. The form of the gap in Sharp Mountain is that of a V, the profile showing no facets (Fig. 79). The ridge crest slopes toward the notch and the sides slope at an angle of about 30° (Fig. 80). The gap in Second Mountain is not quite so symmetrical and is broader and not so steep-sided as the one in Sharp Mountain (Fig. 82). The east side slopes at an angle of about 19°, but the west side is steeper. This difference is accounted for by the fact that the river makes a bend in passing through the gap. The west slope is steeper because it is on the outside of the curve and constitutes the under cut slope (Fig. 82). The sides of the gap in Locust Mountain, as seen from the north, appear to slope at an angle of about 25° to 26° (Fig. 84).

The comparatively high angle of dip of the formations, no doubt is partly responsible for the absence of structural facets in the gaps. Furthermore, the Pottsville conglomerate is rather massive throughout, and alternating soft and hard beds tending to produce structural facets are absent.

In all cases, the ridge crest slopes toward the gaps, indicating superposition of the Little Schuylkill River at a time prior to the Schooley (Kittatinny) cycle, and suggesting that the stream held its course throughout Schooley (Kittatinny) time.

The gaps of this area, like those in the vicinity of Pottsville, are V-shaped and exhibit no facets. The sides slope at an average angle of about 25° and the ridge crests slope gently toward the gaps, meeting them at a rounded angle, which is as a rule much sharper than in the wind gaps. Talus accumulations, so marked in the wind gaps, are not so abundant here.

Water Gaps in the Vicinity of Pottsville

Four picturesque water gaps are present in the region south and west of the city of Pottsville. Above the town of Schuylkill Haven, the Schuylkill River divides into two streams, the West Branch of the Schuylkill and the Schuylkill proper, both of which cut through Second and Sharp mountains, forming four narrow notches in those ridges. The gaps vary in width from one-half to three-quarters of a mile and their depths from

Fig. 83.—Gap cut by Little Schuylkill River through Locust and Nesquehoning mountains. As seen from a point to the south.

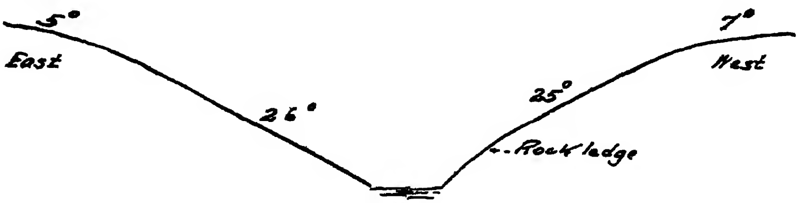

Fig. 84.—Profile of the gap in Locust and Nesquehoning mountains, showing angles of slope. Hor. scale-1 in.—735 ft. Vert. scale-1 in.—550 ft.

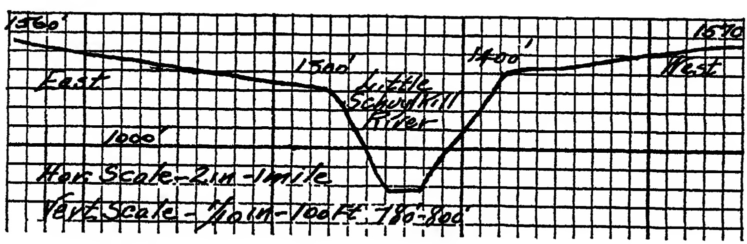

Fig. 85.—Profile of the gap in Locust and Nesquehoning mountains, showing elevations. Taken from the topographic map.

580 to 780 feet, their elevations above sea level ranging from 580 to 680 feet.

Sharp Mountain is made up of the Pottsville conglomerate. In the vicinity of Pottsville and at the point where Swatara Creek crosses it,

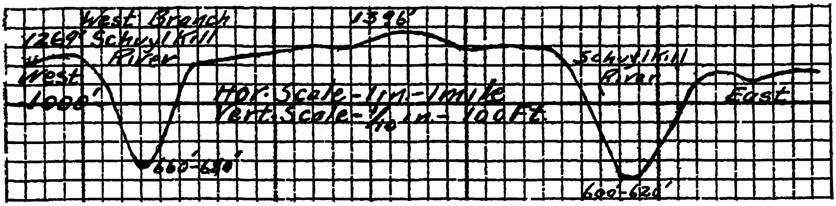

FIG. 86.—Profile of the gaps cut by the Schuylkill River and the West Branch of the Schuylkill River through Sharp Mountain, showing elevations. From the topographic map.

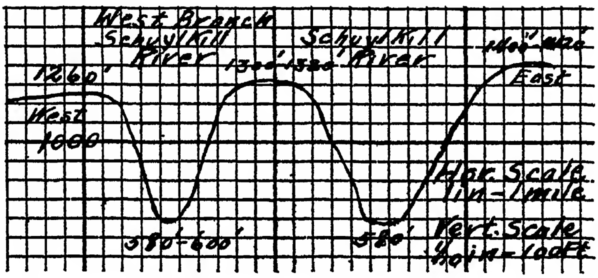

FIG. 87.—Profile of the gaps cut by the Schuylkill River and the West Branch of the Schuylkill River through Second Mountain, showing elevations. Taken from the topographic map.

FIG. 88.—Profile of Schuylkill Gap in Second Mountain, showing angles of slope. Hor. scale-1 in.—1400 feet. Vert. scale-1 in.—875 feet.

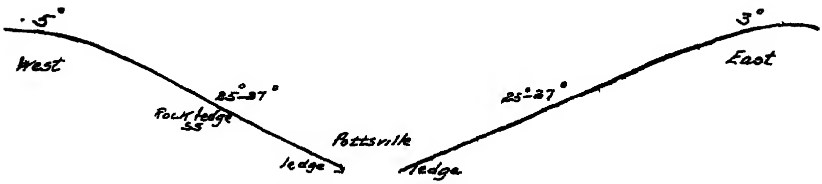

FIG. 89.—Profile of Schuylkill Gap in Sharp Mountain, showing angles of slope. Hor. scale-1 in.—1000 feet. Vert. scale-1 in.—1000 feet.

north of Pine Grove, the formation stands almost vertical with the lower coal beds on one side of it and the red shale on the other.

The gap at Pottsville, through which the main Schuylkill flows, has a very regular profile. A sketch from the south (Fig. 89) shows the angle of both slopes, determined by means of a Brunton compass, to be from 25° to 27°. The ridge crest on the west side slopes toward the gap at an angle of about 5°. On the east side the general slope of the ridge crest, from a point three miles east of Schuylkill River, is toward the gap and attains an angle of 3° near the notch. No facets appear in the outline of this notch and its nearly straight sides seem to be without irregularities.

The other water gap in Sharp Mountain (Fig. 90) was cut by the West Branch of the Schuylkill. Its profile as seen from the north has the outline of a nearly perfect V and is almost smooth and free from irregularities due to rock outcrops. The west side has a maximum slope of about 20°, and grades upward by a continuously convex slope into the ridge crest; the east side appears to be slightly convex and somewhat steeper, being about 25°. The change of slope is rather abrupt where the sides of the gap merge into the upland. On the east side the ridge crest has a slope of a few degrees toward the notch. The ridge crest (Fig. 86) slopes from a higher point, located approximately midway between the two streams. This point marks the position of the old divide, which was established on the Schooley (Kittatinny) surface.

A sketch (Fig. 88) was made of the water gap cut by the main Schuylkill River through Second Mountain. Viewed from the north, this gap presents a profile which, like the others in Sharp Mountain, is nearly a perfect V in outline. The angle of slope of the sides is about the same as that of the other gaps, the west side being about 25° and the east side approximately 26°. The straight sides of the gap grade into the ridge crest rather abruptly and by a rounded angle. The slope of the ridge crest is toward the gap on both sides.

The Pocono sandstone makes up the north half of Second Mountain and is well exposed in the Pennsylvania Railroad cut on the east side of the gap. The beds are almost vertical, 75° to 80°, and consist of a hard, resistant, thick-bedded, massive sandstone.

The remaining gap to be discussed is the one cut by the West Branch of the Schuylkill through Second Mountain. The sketch of this notch (Fig. 91), based on a photograph taken from a point to the south of the ridge, shows the gap with sides somewhat convex, and merging by a rounded slope and by a rather abrupt angle into the ridge crest. The east side is the steeper, having an angle of 30° near the bottom, whereas

the west side slopes more gently, 27°. The slope on the east side grades upward, by a continuously convex curve, into one of 21° and finally 10°, merging gradually into the upland. On the west side the slope of 27° decreases upward by a continuously convex slope into one of 11° and finally into one of but 2° on the ridge crest. No facets appear in the profile of the gap.

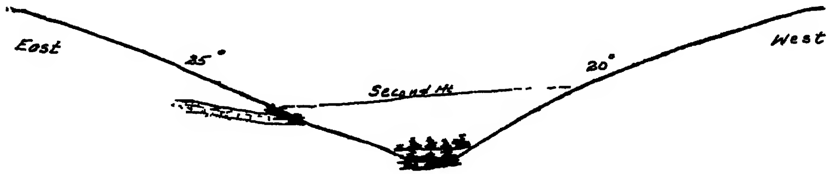

Fig. 90.—Profile of the gap cut by the West Branch of the Schuylkill through Sharp Mountain, showing angles of slope. Profile taken from a photograph.

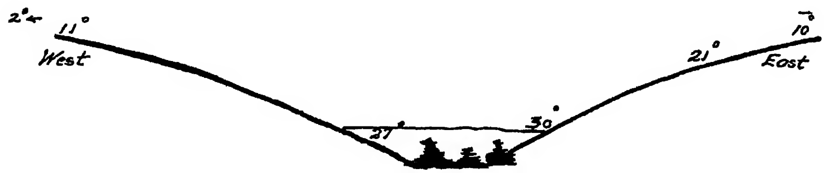

Fig. 91.—Profile of the gap cut by the West Branch of the Schuylkill River through Second Mountain, showing angles of slope. Profile taken from a photograph. Angles measured from a point directly in line with the gap.

In conclusion the writer wishes to emphasize the fact that no facets are present in the profiles of the group of four water gaps near Pottsville. This is attributed to the fact that the rock formations are vertical or nearly so, thereby strengthening the writer's theory that the facets appearing in the gaps of the Appalachians are the result of rock ledges that lie at a sufficiently low angle of dip to produce angularities in their profiles. The average angle of slope of the sides of the gaps is about 25°, which is steeper than in the wind gaps. The sides in all cases make a much sharper angle with the ridge crest than do the wind gaps.

Schuylkill Water Gap

Schuylkill Water Gap, called by some the Port Clinton Gap, is located at the point where the Schuylkill River cuts across Blue Mountain. It is one of the most impressive of all the gaps in the Northern Appalachians and with the exception of Delaware Water Gap it is perhaps the most picturesque of them all (Fig. 92).

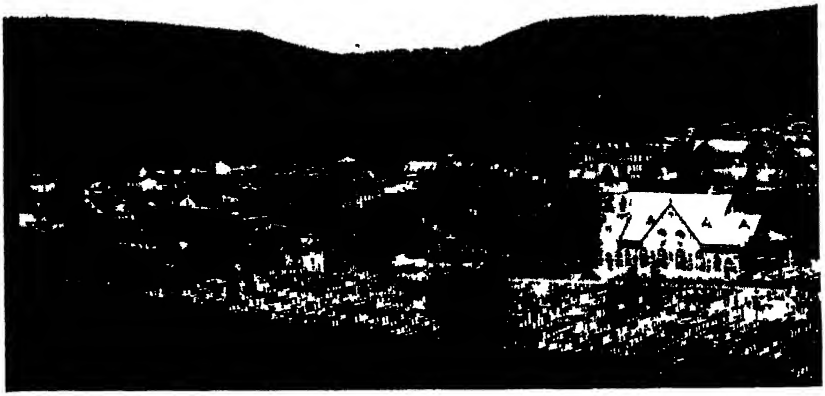

FIG 92.—Schuylkill Gap from the south. View from the town of Hamburg.

FIG. 93.—Profile of Schuylkill Gap as seen from the town of Hamburg Taken from the photograph above. View at a slight angle. The angles of slope are nearly correct when compared with those in Fig. 96.

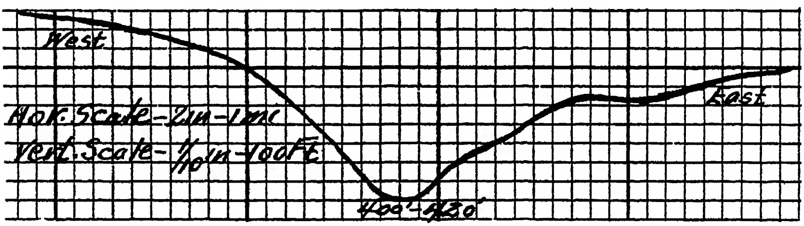

FIG. 94.—Profile of Schuylkill Gap, showing elevations. Taken from the topographic map.

Schuylkill Gap is about a mile wide across the top and between 600 and 700 feet wide at the bottom. Its floor has an elevation of 400 to 420 feet A. T., more than a thousand feet below the crest of the ridge on the west side, making this notch one of the deepest in the Northern Appalachians.

The formations in Schuylkill Gap dip to the northwest at a high angle, 78° to 83°, being nearly perpendicular (Fig. 97). It is obvious that in this case the hard Oneida conglomerate and Medina sandstones stand at such a high angle that it would be difficult to attribute the existence of

facets to an alternating series of hard and soft rock beds. A very prominent ledge of hard, resistant sandstone outcrops in the gap and disappears beneath the river. This sharp ledge is quite conspicuous on the west side of the notch and has a high angle of dip to the northwest, but does not produce a facet in the profile.

On the east side of the gap, at an elevation of about 960 feet A. T., the slope is downward toward the east for a distance, whereupon the trend

FIG. 95.—Schuylkill Gap from the south.

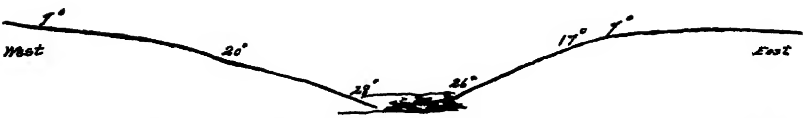

FIG. 96.—Profile of Schuylkill Gap, taken from the photograph above. Angles of slope measured in the field.

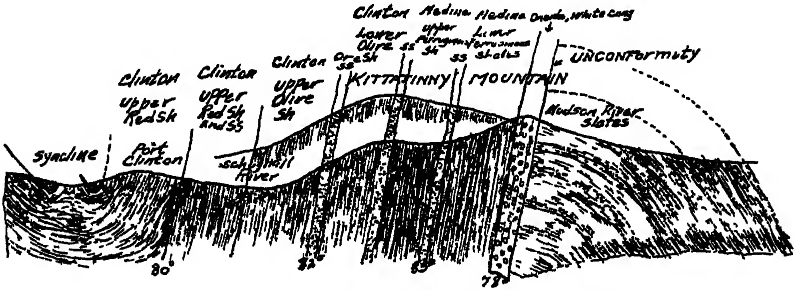

FIG. 97.—Structure section of Blue Mountain at Schuylkill Gap. (Penn. Survey.)

is again upward toward the crest of the ridge. The lower elevation of the ridge, above 960 feet A. T. on the east side of the gap, can be attributed to the fact that the Schuylkill River makes a great bend near the point where it leaves the notch. The undercut slope on the outside of the great curve is quite steep. Apparently the river has cut away a large part of the ridge and narrowed it to a greater extent; the amount removed is indicated by the width of the ridge on the west side. Where the ridge crest is narrow, erosion has lowered it to a greater degree, for the amount of erosion of a tilted formation varies inversely as the thickness. The ridge crest on the outside of the great curve has been shifted northward and is out of line with the general trend of the divide marked by the top of Blue Mountain. The abrupt change in slope on the east side cannot be attributed to a hard rock bed, for the beds stand nearly vertical, nor is it a facet due to a still-stand of the land, during which peneplanation took place. The profile of the gap on the west side is quite uniformly curved, merging gradually by a continuously convex slope into the ridge crest, which has a decided inclination toward the gap. The slope of the ridge crest toward the gap on both sides of the river marks the old valley established by the Schuylkill River on the Schooley (Kittatinny) peneplane and signifies that the stream was superposed in a cycle earlier than the Schooley (Kittatinny) and held its course throughout Schooley (Kittatinny) time.

That Schuylkill Gap, one of the largest and deepest water gaps in the Appalachians, has no facets in its profile is significant in view of the fact that the hard rock beds stand nearly vertical, whereas in Delaware and Lehigh gaps, where facets are present, they have a much lower angle of dip. It seems to the writer that there is abundant evidence to prove that structural facets are due to the presence of hard rock beds which dip at an angle sufficiently low to hold up the weaker beds below them.

Water Gaps North of Pine Grove

About three or four miles north of the town of Pine Grove, Swatara Creek and two of its tributaries, Lorberry and Rausch creeks, have cut through Sharp and Second mountains, forming four deep gaps.

The structure of the formations is like that in the Tamaqua and Pottsville areas. Sharp Mountain is composed of the Pottsville conglomerate, which stands nearly vertical where the Swatara cuts through it. At Second Mountain the Pocono sandstone dips at a high angle, about 65°, to the northwest.

FIG. 98.—The gap cut by Swatara Creek through Second Mountain. View from a point to the south, near the town of Cherryville.

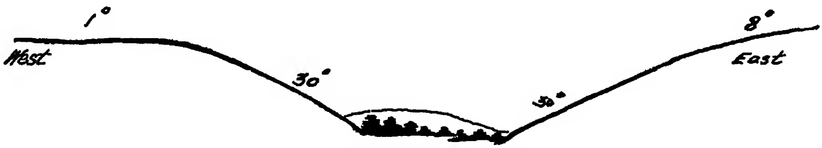

FIG. 99.—Profile of the gap cut by Swatara Creek through Second Mountain, taken from the photograph above. Angles obtained in the field from a point directly in line.

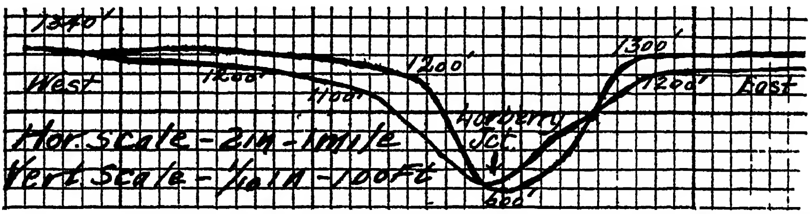

FIG. 100.—Profile of Swatara Gap through Second Mountain, showing elevations. From the topographic map.

The most important of the water gaps in the Pine Grove area is that cut by Swatara Creek through Second Mountain. This gap is nearly a mile long, about the same distance in width at the widest place and is 700 feet deep. The ridge on both sides of the notch is divided longitudinally into two parts by two deep narrow valleys, one of which, on the eastern side, is called Adam's Run. Viewed from the south, near the town of Cherryville, this gap is seen to be quite symmetrical (Fig. 98). Its sides at their steepest point, near the bottom, have a maximum angle of 30°, which diminishes upward by a continuously convex slope, merging into the ridge crest at a rather sharp, rounded angle. No facets appear in the profile, although a rather prominent ledge of sandstone juts out from the east side, forming at one point a lookout from which may be

obtained a fair view of the region to the south and north of Second Mountain.

The writer was unable to obtain photographs of the other three gaps in Sharp Mountain. A view of the Rausch Creek gap, obtained from the

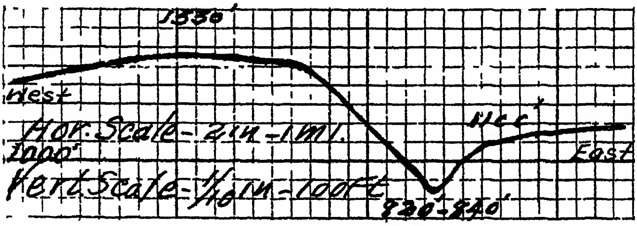

FIG. 101.—Profile of the gap cut by Lorberry Creek through Sharp Mountain, showing elevations. Taken from the topographic map.

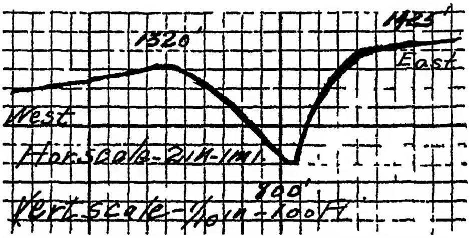

FIG. 102.—Profile of the gap cut by Rausch Creek through Sharp Mountain, showing elevations. From the topographic map.

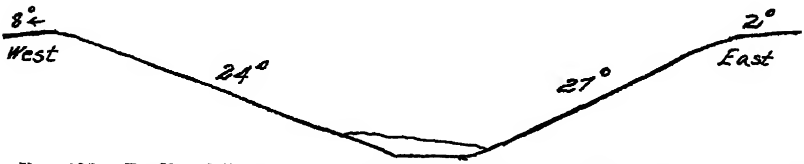

FIG. 103.—Profile of the gap cut by Rausch Creek through Sharp Mountain, showing angles of slope. Hor. scale-1 in.—725 feet. Vert. scale-1 in.—750 feet.

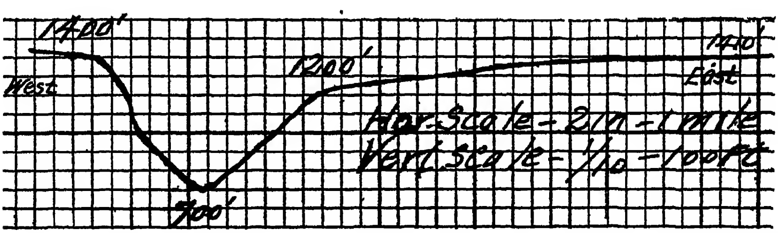

FIG. 104.—Profile of the gap cut by Swatara Creek through Sharp Mountain, showing elevations. Taken from the topographic map.

state highway at a point about a mile south of the ridge, presents a profile the east side of which is the steeper. This is probably due to the curve in the creek where it cuts through the mountain. The west side slopes at a maximum angle of about 24°, and the east side has an angle of approximately 27°. On the west side the ridge crest slopes at an angle of 8° toward Lorberry Gap, the most western gap of the three. On the east side the ridge crest has a gentle slope toward the gap, the profile of which exhibits no facets (Fig. 103).

Swatara Gap in Sharp Mountain is almost a perfect V. The sides slope to a maximum angle of about 25° and the ridge crest slopes toward the gap, which like the other gaps has no facets in its profile (Fig. 104). Lorberry Gap, the most western one, is not so symmetrical as the others (Fig. 101). Its eastern slope flattens out at an elevation of about 1100 feet A. T. and forms the ridge crest, which slopes westward from Rausch Creek Gap, where it has an elevation of 1340 feet A. T. On the western side of the notch, the ridge attains an altitude of 1530 feet A. T. The sides of the gap slope at an angle of about 25°.

The water gaps north of Pine Grove exhibit the same features, characteristic of those at Pottsville and Tamaqua, where similar structural conditions prevail, such as a high angle of dip of the beds. The profiles of the gaps do not show facets, the ridge crests in general slope toward the gaps, make abrupt angles with them, and the sides slope at an average angle of about 25°.

One feature that it quite important in connection with a study of water gaps is their widely differing elevations. In the Pottsville area the gaps vary in elevation from 580 to 660 feet A. T., in the Tamaqua district from 720 to 780 feet A. T., and in the vicinity north of Pine Grove five gaps have a range in elevation ranging from 600 to 820 feet A. T. Surely there is no accordance in the altitudes of the water gaps in the Northern Appalachians.

Swatara, Indiantown and Manada Water Gaps

Deep, symmetrical, V-shaped notches have been cut through Blue Mountain at the points where Swatara, Indiantown and Manada creeks cross the ridge.

The succession of formations is the same at all the gaps, the Martinsburg slates being the lowest formation exposed. Upon them lie successively the Oneida and Medina sandstones, the Clinton shales, Lewistown limestone, Oriskany sandstone, Hamilton shale, Portage flags, Chemung shale and the Catskill red sandstone; Second Mountain, the

FIG. 105.—Swatara Gap from the south. From a point a short distance north of the town of Lickdale.

FIG. 106.—Profile of Swatara Gap, taken from the photograph above. Angles obtained in the field from a point directly in line with the gap.

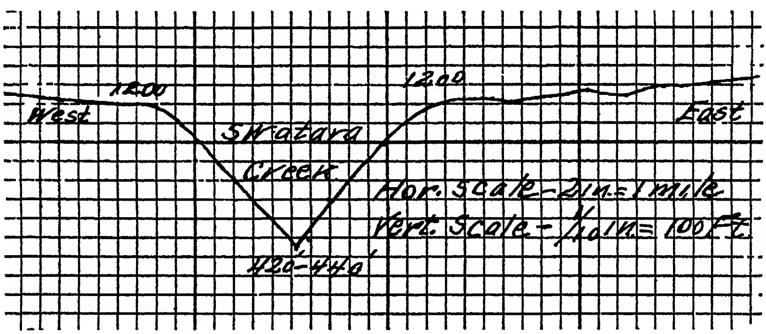

FIG. 107.—Profile of Swatara Gap, showing elevations. From the topographic map.

next ridge north of Blue Mountain, is composed of the Pocono sandstone. Sharp and Stony mountains are capped with the hard Pottsville conglomerate, upon which, farther east, lie the coal measures.

The structure at the Susquehanna River is that of a huge overturned syncline. The formations from Clark's Creek down through Second Mountain and Blue Mountain are thrown over on their faces 20° beyond the vertical, so that they dip southward 70°. The overturn continues eastward into Lebanon County. At Swatara Gap, the Martinsburg slates,

Oneida and Medina sandstones and Clinton shales, which outcrop in the notch, are almost vertical, the angle of dip measuring 76° to 78° to the northwest. At Indiantown and Manada gaps the beds are almost vertical; the overturned condition of the formations at the Susquehanna, gradually changing to vertical, becomes a regular but very steep northward dip at Swatara Gap.

Swatara Gap has a width across the top of about three-quarters of a mile but its bottom is very narrow. The depth of the notch averages 770 feet. This is the mean difference between its altitude at the bottom, which is from 420 to 440 feet A. T., and 1200 feet A. T., the elevation on the ridge crest.

The sides of the notch are quite convex (Fig. 106), grading by continuously convex slopes into the ridge crest. The west side has a maximum angle of inclination of 24°. This changes gradually to one of 4°, grading by a continuously convex curve into the upland, which slopes gently toward the gap at an angle of but 2°. The steepest angle of slope on the east side is 22° and changes gradually by a convex slope to one of 7° near the ridge crest, which on the west side slopes at an angle of 2° toward the gap.

A glance at the profile of Swatara Gap (Fig. 105) is sufficient to convince one that facets are not present. Conspicuous rock ledges such as those in Delaware and Lehigh water gaps appear to be absent.

The width of Indiantown Gap across the top is about one mile; at the bottom it is narrow, possibly only a few hundred feet wide. The depth of the notch is approximately 640 feet and its elevation is 560 feet A. T. Its eastern side is the steeper, the maximum angle being 25°, grading by a continuously convex slope into one of 17°, finally merging into the ridge crest, which has a long, gentle slope of 2° toward the gap. The west side has in the lower part of the notch a maximum slope of 20°, grading upward by a continuously convex slope into one of 10°, merging into the ridge crest, which has a slope of 3°. No facets are present in the profile (Fig. 108).

Question arises concerning the absence of gaps in Second, Sharp, Stony and Peters mountains to the north. Indiantown Gap, a large notch, is occupied by a very small stream. Why is this stream so small and why are there no gaps in Second Mountain to the north? A possible explanation for the absence of water gaps in the ridges to the north is that the subsequent streams, Clark and Stony creeks, accomplished the capture of the headwaters of the creeks which occupied Heckert, Manada and

FIG. 108.—Indiantown Gap as seen from a point about one and one-half miles directly south.

FIG. 109.—Profile of Indiantown Gap, taken from the photograph above. Angles measured in the field from a point directly in line with the gap.

FIG. 110—Profile of Indiantown Gap, showing elevations Taken from the topographic map.

Indiantown gaps, at a time shortly after the uplift of the Schooley (Kittatinny) surface. There are no wind gaps of any consequence in Second Mountain, in line with these streams, marking former stream courses across the ridge. All the wind gaps are very shallow ones and there might be some doubt as to whether they are cols or true wind gaps. There is not much evidence for believing that the streams occupying Manada and Indiantown gaps ever extended northward across Second Mountain and the ridges beyond. However, if piracy occurred shortly after the uplift of the Schooley (Kittatinny) surface, deep wind gaps would not be expected to occur in Second Mountain. Furthermore, erosion and weathering may have worn the shallow gaps away or at least partially destroyed

them. It must be admitted that the creek occupying Indiantown Gap is a very small one. It is probable that Manada and Trout creeks, tributaries of the Swatara, have robbed it of some of its headwaters. Even if the Indiantown creek were restored to its original size, it would still be a small stream. Apparently a small stream can cut a deep, wide gap, provided the conditions are favorable.

Manada Gap is about three-fifths of a mile wide at the top and possibly several hundred feet across at the bottom. The elevation of its floor is 540 feet A. T. and the ridge crest on the west side attains 1100 feet A. T., making the gap about 560 feet deep.

The profile of Manada Gap is not as symmetrical as the majority of water gaps in the Northern Appalachians, the east slope being much steeper than the west side. At an elevation of about 900 feet A. T. the east side flattens out, sloping downward to the east at first and then by a gentle upward slope into the ridge crest (Fig. 113). This feature might be interpreted by some as a facet or an old valley slope between the Schooley (Kittatinny) and Harrisburg levels. Another explanation can be offered for this feature, which appears only on the east side of the gap. It will be noted that the ridge on this side is divided longitudinally by a small stream, which is about three-fourths of a mile long. The ridge crest has been narrowed and as a result more rapid erosion has lowered it below what it would be without the stream, probably 1100 feet A. T., which is the elevation on the west side (Fig. 114). The east side of the notch has a maximum angle of 30° at the bottom, decreasing by a continuously convex slope upward into one of 18°. The ridge crest on this side slopes toward the gap at an angle of about 7°. On the west side, near the floor of the notch, the angle of slope is 18°, grading by a continuously convex slope into one of 11°. The ridge crest slopes toward the gap at a low angle, only 2°.

A study of the profiles of the gap is sufficient to convince one that facets, due to stillstands of the land during which peneplanation took place, are absent. In fact no facets of any kind occur and their absence is in accordance with the belief of the writer that, where they do occur, they are structural and are due to resistant ledges of rock which stand at sufficiently low angles of dip to produce angularities in their profiles.

The photographs and profiles show long, gentle slopes of the ridge crest toward the gaps, indicating that the streams were superposed across Blue Mountain at a time earlier than the Schooley (Kittatinny) cycle and held their courses throughout Schooley (Kittatinny) time.

FIG. 111.—Manada Gap as seen from a point about a mile north of Blue Mountain.

FIG. 112.—Manada Gap as seen from the Great Valley to the south of Blue Mountain.

FIG. 113.—Profile of Manada Gap, showing angles of slope. Taken from the photograph above. Obtained from a point directly in line with the gap.

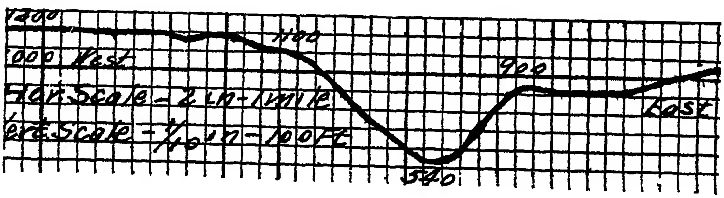

FIG 114.—Profile of Manada Gap, showing elevations. Taken from the topographic map.

WATER GAPS OF THE SUSQUEHANNA RIVER THROUGH BLUE, SECOND, PETERS, BERRY AND MAHANTANGO MOUNTAINS

From Harrisburg northward the Susquehanna cuts through a succession of ridges, forming a series of picturesque water gaps. The first of these notches is the one in Blue Mountain near the city of Harrisburg (Fig. 115). Here the structure is that of a monocline. From the town

FIG 115.—Susquehanna Gap through Blue Mountain as seen from the north. View from the town of Marysville.

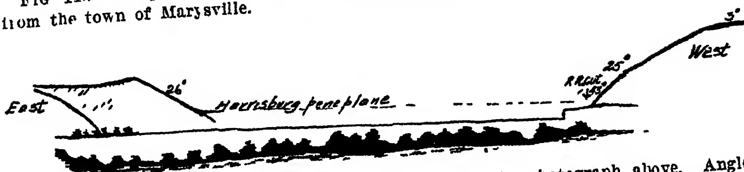

FIG 116.—Profile of Susquehanna Gap, taken from the photograph above. Angles measured in the field from a point to the north of the gap.

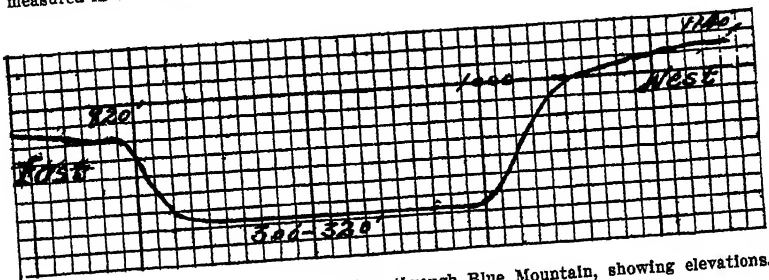

FIG. 117.—Profile of Susquehanna Gap through Blue Mountain, showing elevations. Taken from the topographic map.

of Halifax to the north of Clark's Creek the formations dip south at an angle of about 45°. From Clark's Creek down through Second Mountain and Blue Mountain gaps the formations are thrown over on their faces 20° beyond the vertical, so that they dip southward 70°, affording a superb section. In the Blue Mountain gap the Martinsburg slate is the lowest formation exposed and above it lies the resistant Shawangunk conglomerate and sandstone, which constitute Blue Mountain. The younger formations outcrop in succession northward, as follows: Clinton shale, Hamilton shale, Portage flags, Chemung shale, Catskill red sandstone, Pocono sandstone and the Mauch Chunk red shale.

Peters Mountain lies north of the axis of the overturned syncline; the Pocono formation dips south from the great arch anticline called Broad Mountain. In Berry and Mahantango mountains the Pocono sandstone

dips northwest and southeast, for the ridges constitute the north and south limbs of a syncline.

The altitude of the bottom of the Blue Mountain notch is only 300 to 320 feet A. T., giving it a depth of 800 feet below the ridge crest on the west side, where the elevation is approximately 1100 feet A. T. Across the top, Susquehanna Water Gap attains a breadth of nearly one and one-half miles. Its width at the bottom, where the railroad bridge crosses the river, is a little more than five-eighths of a mile, making it the broadest notch in the Northern Appalachians. Seen from the north, at a point near Marysville, the sides of the gap appear to be quite steep (Fig. 116). Measured by sighting a Brunton compass, the west side appears to have a slope of about 25°. At the bottom of the gap near the railroad cut the slope is steeper, 43°. The east side, when sighted from positions north and south of Blue Mountain, has an angle of slope of about 25° to 26°. Both sides have angles of slope which are about the average for all the water gaps in the Northern Appalachians. On the east the ridge crest, which has an altitude of 800 feet A. T., makes a sharp angle with the slope of the gap, whereas the west side grades by a continuously convex slope into the ridge crest.

No facets are visible in the profile of the notch, the formations standing at too high an angle to allow alternate beds of hard and soft rock to produce angularities.

The ridge crest on both sides of the river slopes toward the gap at low angles of about 3° to 6°. Blue Mountain has an elevation of only 800 feet A. T. on the east side, at least 200 feet below the ridge crest on the west side: The reason for this is obvious, a small stream flowing longitudinally in an east-west direction has narrowed Blue Mountain, resulting in a lower elevation. What might be interpreted as a facet due to peneplanation, at an elevation of about 800 feet A. T., is therefore the result of other factors.

It seems probable that the Susquehanna was already the major stream on the Schooley (Kittatinny) peneplane and that the land sloped toward it as it would in any drainage basin. The crest of Blue Mountain rises in a northeasterly direction, to a point nearly midway between Swatara and Schuylkill water gaps, where the elevation attains from 1680 to 1700 feet A. T. This appears to be the point which marked the broad divide on the Schooley (Kittatinny) peneplane, between the Schuylkill and Susquehanna drainage basins. West of the Susquehanna the elevation of the ridge crest increases in a southeasterly direction to the point where Blue Mountain ends. It is very improbable that the Susquehanna River could

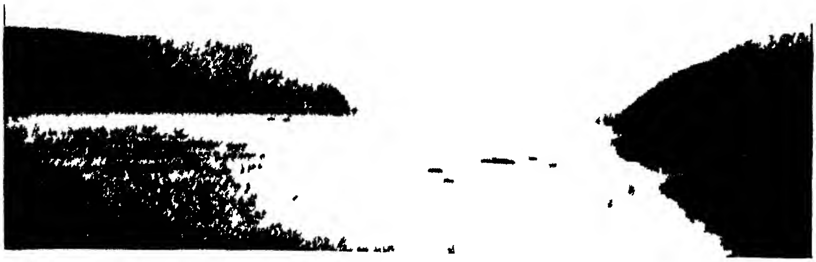

FIG. 118.—The gap cut by the Susquehanna River through Second Mountain. View from the Pennsylvania Railroad bridge at Rockville.

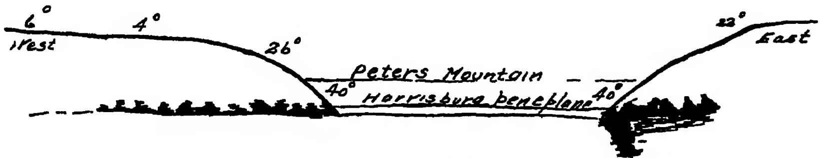

FIG. 119.—Profile of the Susquehanna Gap through Second Mountain, taken from the photograph above. Angles measured in the field from a point directly in line with the gap.

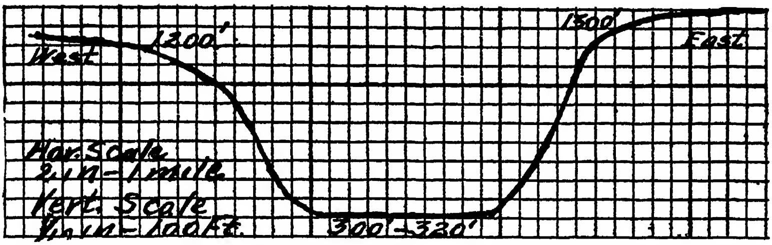

FIG. 120.—Profile of the Susquehanna Gap through Second Mountain, showing elevations. Taken from the topographic map.

have shifted its course on the Schooley (Kittatinny) peneplane from a point west of the apex of the syncline to its present position. A study of the ridge crests has convinced the writer that little shifting of the streams on the Schooley (Kittatinny) peneplane occurred, in view of the fact that the streams occupied rather deep valleys with long gentle slopes making wholesale shifting or migration across the ridges impossible. The Delaware, Lehigh, Schuylkill and Susquehanna rivers were all at a level far below the divides, which mark the highest points on the ridge crests. The streams were therefore superposed in a cycle earlier than the Schooley (Kittatinny) and held their courses throughout Schooley (Kittatinny) time.

FIG. 121.—East wall of the gap cut by the Susquehanna River through Second Mountain.

Near the town of Dauphin the Susquehanna River has cut a deep notch through the Pocono sandstone ridge, Second Mountain (Fig. 118). Here the dip of the beds is about 65° to 70° to the south (Fig. 121).

The floor of Second Mountain Gap is from 900 to 1000 feet below the level of the Schooley (Kittatinny) peneplane, the distance below the ridge crest. The width of the notch across the top is approximately a mile and one-quarter, and at the bottom a little more than one-half a mile.

The profile of the gap, seen from the bridge at Rockville to the south, appears to have sides which are convex in outline (Fig. 119). The maximum slope on the east side is about 40°, grading by a continuously convex slope into an angle of about 22° near the ridge crest. On the west side, in the lower part of the notch, the maximum slope is approximately 40°, grading by a convex slope into an angle of about 26° near the top.

Very little debris is present on the slopes of the gap; they are quite bare and rock outcrops are prominent. The only angularity seems to be at the points where the two erosion surfaces meet, represented by the sides of the gap and the slopes on the ridge crest. The absence of facets in the profile is significant, in view of the fact that the beds stand at so high an angle. It is probable that angularities in the profile would appear if the strata stood at a low enough angle, because alternate hard and soft beds, which produce facets, are present here.

There are long, gentle slopes toward the gap on the ridge crest on both sides of the river; the angles are approximately 3° to 5°.

Near the town of Duncannon, the Susquehanna River has carved a deep notch through Peters Mountain (Fig. 122). This ridge is composed of

FIG. 122.—Gap cut by the Susquehanna River through Peters Mountain. From the south at a slight angle.

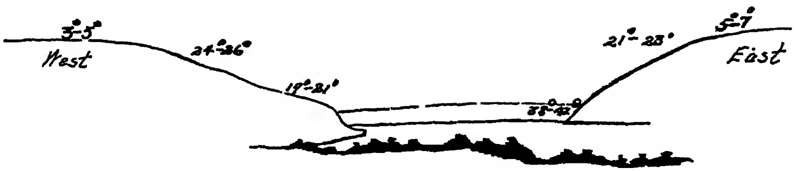

FIG. 123.—Profile of Susquehanna Gap through Peters Mountain, taken from the photograph above. Angles of slope measured from points directly in line with the gap.

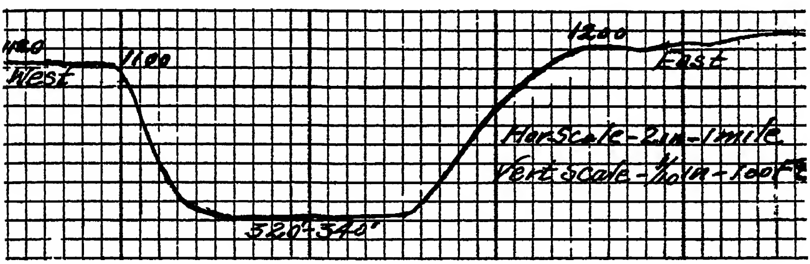

FIG. 124.—Profile of Susquehanna Gap through Peters Mountain, showing elevations. Taken from the topographic map.

the hard, resistant Pocono sandstone, also responsible for Second Mountain several miles to the south. The dip of the slabby, sandstone beds at the gap is about 45° to the south.

Peters Gap is about 870 feet deep; it is that distance to the bottom from the ridge crest on the east side. The width across the top is about one and one-quarter miles, and at the bottom approximately one-half

mile. Seen from the south, the east side of the notch appears to be decidedly convex. At the bottom of the gap the maximum angle of slope is about 38° to 42°, while at the top it is approximately 21° to 23°, grading upward from one angle to the other by a continuously convex slope. The profile of the west side is a slightly concave one, broken only by a small angularity or hump, due to a concealed ledge of rock. The series of hard and soft beds and the comparatively low angle of dip, 45°, may explain the presence of the ledge. The west side has an angle of about 19° to 21° at the bottom of the gap, but farther up, near the top, the angle is somewhat greater, 24° to 26°. The profile taken from the topographic map (Fig. 124) indicates that the west side is the steeper. The reason for this is apparent: the Susquehanna River makes a curve through the gap, and the western side can be interpreted as the undercut slope. With the exception of the slight angularity in the profile on the west side the slopes are quite regular, no facets appearing.

There are the usual long, gentle slopes of the ridge crest toward the gap, the sides of which meet it at rather abrupt angles, a condition common to all water gaps.

The Berry Mountain Gap is located about two miles south of the town of Millersburg (Fig. 125). It is one of the five large water gaps cut by the Susquehanna River through the Shawangunk and Pocono ridges, which here form the ends of two narrow synclines. In Berry and Mahantango mountains the Pocono sandstone dips northwest and southeast, for the ridges constitute the north and south limbs of a syncline. The dip of the sandstone is about 65° to 70° to the northwest, where it outcrops in the cuts along the paved highway within the Berry Mountain Gap. The same formation dips 50° to the southeast in the Susquehanna Water Gap through Mahantango Mountain, located four miles farther north.

The Berry Mountain notch is approximately one and one-quarter miles wide across the top and two-thirds of a mile wide at the bottom. Its depth below the ridge crest on the west side is about 670 feet, also the depth below the Schooley (Kittatinny) peneplane.

Seen from the north at a point on the south slope of Mahantango Mountain near the Susquehanna and at a slight angle, the Berry Mountain Gap presents a profile without facets (Fig. 126). Both sides slope at apparent angles of about 35° to 40°, a figure above the average for water gaps in the Northern Appalachians. Although the west slope appears to be slightly concave, one is impressed by the straight sides of this gap. This is in accordance with the theory that high angles of dip are not favorable

FIG. 125.—Gap cut by the Susquehanna River through Berry Mountain. View from Mahantango Mountain.

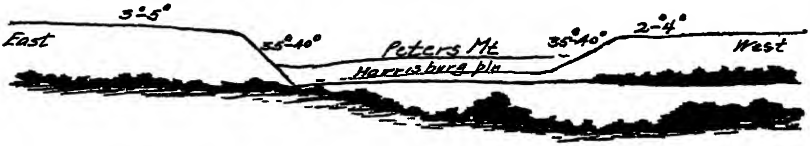

FIG. 126.—Profile of the gap cut by the Susquehanna River through Berry Mountain, taken from the photograph above.

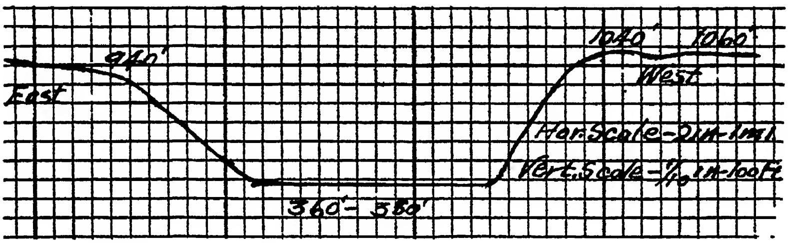

FIG. 127.—Profile of the gap cut by the Susquehanna River through Berry Mountain. showing elevations. Taken from the topographic map.

for the production of structural facets. The topographic map (Millersburg quadrangle) reveals a steeper slope on the west than on the east side (Fig. 127), explained by the curved course of the stream where it passes through the gap. The photograph and profile (Fig. 126) do not show the steeper slope on the west side, because the line of view is at a slight angle to the notch.

The ridge crest slopes at low angles of not more than 5° toward the gap; they are clearly shown on the photograph and profile.

South of the town of Liverpool, at the point where the Susquehanna River makes a sharp bend to the east, a deep gap has been cut through Mahantango Mountain (Fig. 128). At a point along the Pennsylvania Railroad, which passes through the gap, the Pocono sandstone outcrops show a dip of about 50° to 55° to the south. The floor of Mahantango Gap lies about 630 feet below the ridge crest on the east side. Its width

FIG. 128—Susquehanna Gap through Mahantango Mountain. View from Berry Mountain three miles to the south.

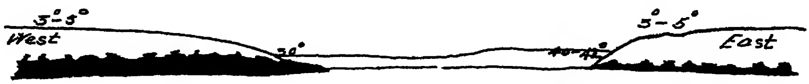

FIG 129.—Profile of the Susquehanna Gap through Mahantango Mountain, taken from the photograph above. Angles measured in the field.

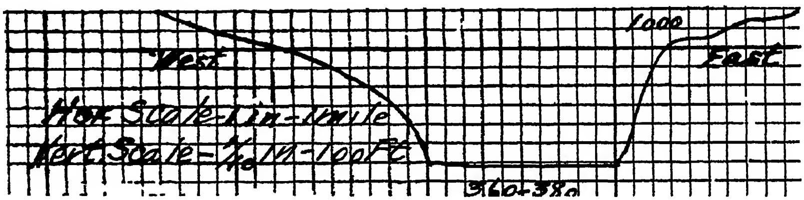

FIG. 130—Profile of the Susquehanna Gap through Mahantango Mountain, showing elevations. From the topographic map.

at the bottom is one-half of a mile and across the top about one and one-quarter miles.

From Berry Mountain about three miles south and at a point directly in line with the gap, an excellent view may be obtained (Fig. 129). The east side is the steeper, having a maximum angle of about 40° to 42° at the base, grading by a continuously convex curve up to the top, where it makes a rather sharp junction with the ridge crest. The west side has a maximum angle of about 30° at the bottom, grading upward by a continuously convex slope into the ridge crest, which ultimately flattens to an angle as low as 3° to 5°. The much steeper slope on the east side is readily explained when one examines the topographic map (Millersburg quadrangle) (Fig. 130). The Susquehanna River makes a sharp turn to the northeast and for that reason the west side should be the steeper, for it is the undercut slope. Therefore another explanation is necessary; it will be observed that a small stream flows down the west slope of the notch in an east-west direction, bisecting the ridge and dividing it into

two narrower parts. The rate at which a tilted formation is lowered by erosion depends in part on its thickness and, all other conditions being the same, a narrower ridge is lowered more rapidly. The presence of the stream therefore accounts for the lower elevation of the ridge on the west side, and the long, continuously convex slope into the upper level.

On both sides of the river the slope of the ridge crest is toward the gap; at low angles of from 3° to 5°.

In conclusion the writer wishes to point out a few general facts clearly shown by the study of the gaps. Not much debris has accumulated on the slopes of the notches and bold rock outcrops are common, which is in harmony with the conditions found in the water gaps everywhere. Their sides are constantly refreshed by erosion, and accumulations of debris, which move down the slopes, are swept away by the continual scour of the streams. The constant retreat of the sides, as the streams widen the gaps, produces fairly sharp angles where they meet the ridge crest.

Although the beds are of variable resistance to erosion in all the gaps, rock ledges producing facets are absent, due to a high angle of dip of the beds. The Peters Mountain Gap shows a slight angularity, which is clearly a rock ledge, probably due to a lower angle of dip of the beds, 45°.

Two erosion surfaces are shown in all the gaps, an older, upper one on the ridge crest called the Schooley (Kittatinny), and a younger one represented by the sides of the gaps. The long, gentle slopes of the ridge crests toward the notches is significant since they indicate superposition of the Susquehanna during a cycle earlier than the Schooley (Kittatinny) as well as indicating that the stream held its course throughout Schooley (Kittatinny) time.

Dornsife Water Gap

A deep cleft has been cut through Line Mountain by Mahanoy Creek, at a point about two and one-half miles east of the Susquehanna River and near the town of Dornsife (Fig. 131).

About two miles west of the gap Line and Little Mountains, composed of the Pocono sandstone, meet to form another cove. The axis of this syncline pitches from the apex, located just east of the Susquehanna River, forming a great basin in which lie Shamokin, Carmel and other important mining towns. Briefly, the coal basin is enclosed by two ridges. The other ridge, consisting of the Pocono sandstone, forms Line Mountain to the south and Little Mountain on the north. The inner ridge,

FIG. 131.—Dornsife Gap cut through Line Mountain by Mahanoy Creek. View from a point directly south.

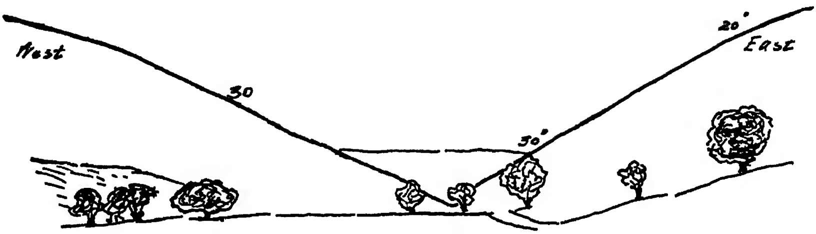

FIG. 132.—Profile of Dornsife Gap taken from the photograph above. Angles obtained in the field from a point directly in line with the gap.

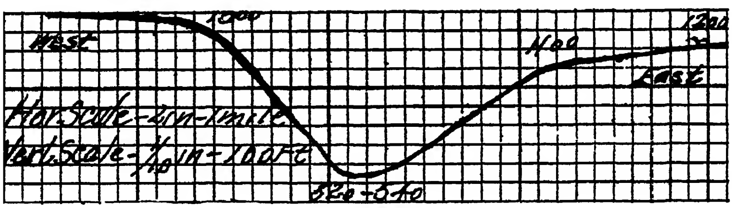

FIG. 133.—Profile of Dornsife Gap from the south, taken from the topographic map.

made up of the Pottsville conglomerate, forms Mahanoy Mountain on the south and Big Mountain to the north. The Pocono sandstone in Line Mountain dips 37° to 40° North, measured at points on outcrops in the gap along the paved road.

Dornsife Gap is about 770 feet deep, and that is also its depth below the Schooley (Kittatinny) peneplane. Its breadth across the top is a little less than a mile and at the bottom it is narrow, a few hundred feet at the most. The elevation of the notch is from 520 to 540 feet A. T.

The profile of Dornsife Gap, as seen from both sides of Line Mountain, looms up conspicuously as a V-shaped, straight-sided notch, the sides of which slope near the bottom at an angle of about 30° (Fig. 132). At about 1100 feet A. T. on the east side and 1300 feet A. T. on the west side, the gap walls meet the ridge crest at rather sharp, rounded angles. The profile (Fig. 133) taken from the topographic map indicates that the west side the steeper of the two. A possible explanation for this is that Mahanoy Creek makes a sharp turn before entering the gap, throwing the stream against the west side, the undercut slope, which, it is logical to suppose, would be the steeper.

No facets are present in the regular contour of the notch. The sides exhibit rock outcrops, because the accumulation of debris is constantly removed by the active stream which occupies the gap. The general slope of the ridge crest is toward the notch.

Water Gaps at Lykens and Wiconisco

Near the towns of Lykens and Wiconisco, Rattling Creek cuts across Berry Mountain and Big Lick Mountain, through two water gaps. The one cut by Rattling Creek through Berry Mountain is referred to by the writer as "Lyken's Gap" (Fig. 134).

The Pocono sandstone, of which Berry Mountain is composed, has a dip of about 50° to the north, as measured at the prominent sandstone ledge known as "Love Rocks." The sandstone here is a thick-bedded, massive formation, which is conglomeratic in places.

Berry Mountain is separated from Broad Mountain by the deep, narrow gorges of the east and west branches of Rattling Creek and constitutes part of the north limb of the Broad Mountain anticline, which at Tower City, eight miles east, plunges beneath the surface. This mountain, capped by the resistant, Pocono sandstone, has no wind or water gaps cutting across it. On the Schooley (Kittatinny) peneplane this arch or monadnock constituted a broad divide, separating the north- and south-flowing streams.

To the north of Berry Mountain lies Lykens Valley, cut in the Mauch Chunk red shales, which dip about 50° to the north. Short Mountain and Big Lick Mountain, north of Lykens Valley, are made up of the very resistant Pottsville conglomerate, which is capped by the coal measures. North of Big Lick Mountain lies Coal or Thick Mountain, also composed of the Pottsville conglomerate. Between the two ridges is a long, nar-

FIG 134.—Gap cut by Rattling Creek through Berry Mountain. View from the colliery on Big Lick Mountain directly opposite Lykens in the distance.

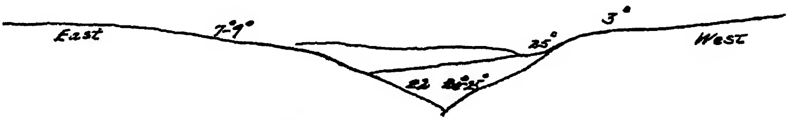

FIG 135 —Profile of the Rattling Creek Gap, taken from the photograph above Angles measured in the field.

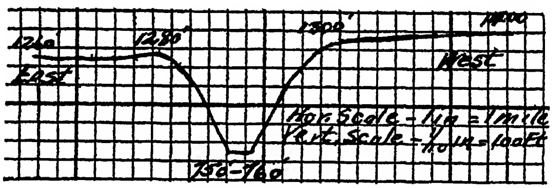

FIG 136 —Profile of the Rattling Creek Gap, taken from the topographic map

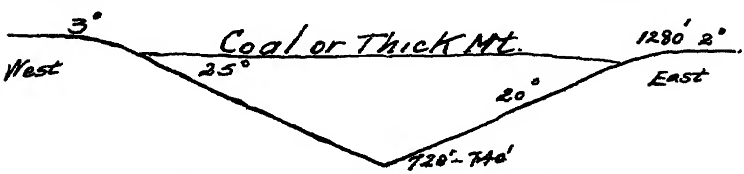

FIG. 137.—Profile of Bear Creek Gap in Big Lick Mountain, showing angles of slope. Obtained from a point directly opposite, on Berry Mountain. Hor. scale 1 in.—1320 ft. Vert. scale 1 in.—750 ft.

row coal basin or syncline, the apex of which is located just east of Loyalton. Here the Pottsville conglomerate rises abruptly from the rolling farm lands on the Mauch Chunk red shales to form the apex of a narrow syncline, the axis of which pitches to the east. It is probable that the

Pottsville ridges constituted low, rounded, elongate monadnocks on the Schooley (Kittatinny) peneplane.

Lykens Gap has an elevation of 740 to 760 feet A. T., a point approximately 550 feet below the ridge crest on the west side. Across the top of the notch the distance is about five-eighths of a mile and at the bottom a few hundred feet. The east side has a maximum angle of slope of about 22° near the bottom, and the west side, which is quite concave in outline, has an angle of about 20° to 25°. No facets are present in the profile of this gap and rock outcrops are numerous and conspicuous.

The ridge crest on the west slopes toward the gaps at an angle of about 3° and on the east at a higher one, approximately 7° to 9° (Fig. 135).

The Wiconisco or Bear Creek Gap is about 700 feet deep, very narrow at the bottom and possibly three-fourths of a mile wide at the top. Seen from "Love Rocks," the rock ledge on Berry Mountain, and a point directly in line with it to the south, it has the profile of a nearly perfect V. The sides are straight, sloping at an angle of 20° on the east and 25° on the west (Fig. 137). The ridge crest meets the gap at rather sharp angles and slopes toward it at low angles of about 2° or 3°. Facets are absent in the profile.

The Lykens and Wiconisco gaps are almost perfect reproductions of those cut by the streams through the Pottsville and Pocono ridges near Pottsville, Pine Grove and Tamaqua. The absence of structural facets in their profiles is in harmony with the theory that a high angle of dip of the formations is not favorable for their production.

Pillow Water Gap

Near the town of Pillow, Mahantango Mountain has been cut through by a narrow, steep-sided notch, which stands out conspicuously against the skyline (Fig. 138).

The Pocono sandstone at the gap has a dip to the south of about 50°, an angle not favorable for the production of structural facets.

Pillow Gap has a depth of about 700 feet, which is also the distance below the Schooley (Kittatinny) peneplane. Across the top the width is approximately one mile and at the bottom one-eighth of a mile, rather large for a stream as small as Deep Creek.

From both sides of the ridge Pillow Gap appears as a symmetrical, V-shaped cleft with nearly straight or slightly convex sides. The east side has a maximum angle at the bottom of 30° and at the top of 25°, grading from one angle to the other by a continuously convex slope. On

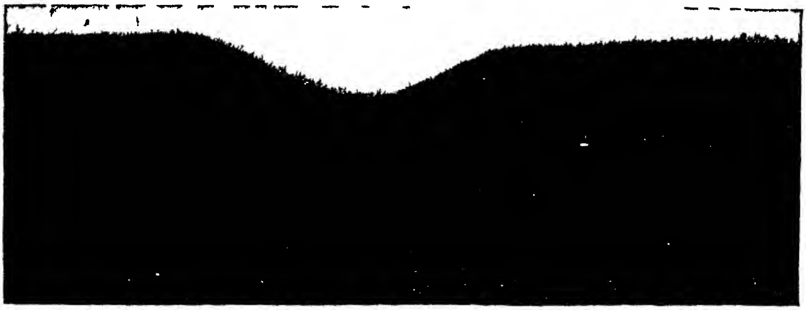

FIG. 138.—Pillow Gap from a point directly north.

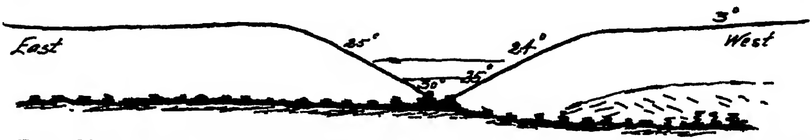

FIG. 139.—Profile of Pillow Gap taken from the photograph above. Angles measured in the field from a point directly in line with the gap.

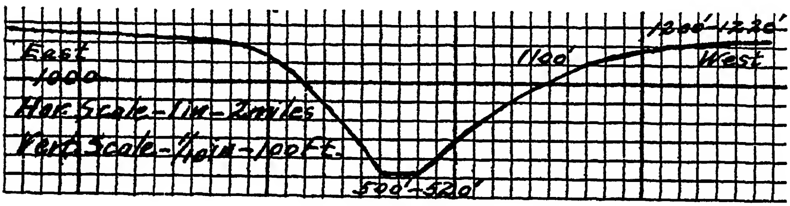

FIG. 140.—Profile of Pillow Gap taken from the topographic map.

the west the angle reaches 25°, somewhat less than on the east (Fig. 139).

Rock ledges outcrop from the sides of the gap, but they are not conspicuous and do not make angularities in the profile, the sides appearing quite smooth and free from irregularities.

The ridge crest forms rather sharp angles with the sides of the gap, and slopes at low angles of from 2° to 3° toward the notch. It rises to the highest elevation on the east, 1420 feet A. T., at a point about one and one-half miles west of the Klingerstown Water Gap. This position marks the divide between the Pillow and Klingerstown streams on the Schooley. (Kittatinny) peneplane. Another divide at 1320 feet A. T. occurs on the ridge crest about one and one-half miles west of Pillow Gap. The long, gentle slopes toward the notches and the divides preserved on the ridge crests signify that the streams which cut Pillow and

Klingerstown gaps were superposed across the ridges at a time prior to the Schooley (Kittatinny) cycle and held their courses throughout Schooley (Kittatinny) time.

A feature which attracts one's attention when studying Pillow Gap, is the small stream which occupies it. The bottom of the notch is very broad, suggesting that Deep Creek was at one time larger than it is at

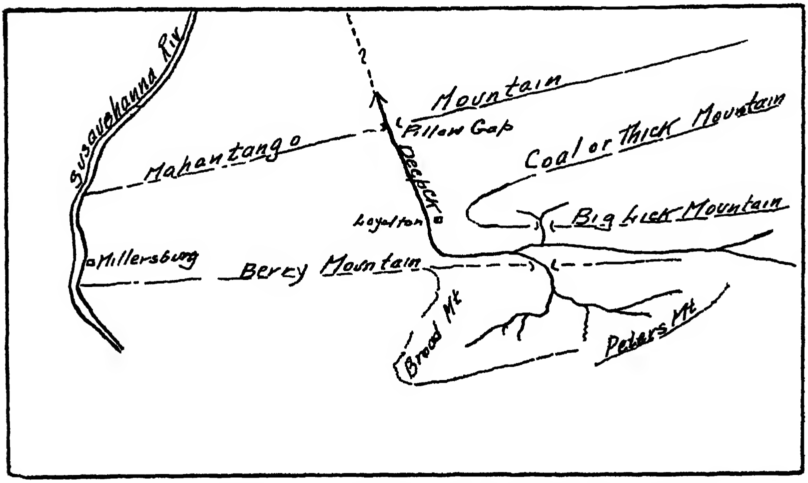

FIG. 141.—Probable course of Deep Creek before piracy took place.

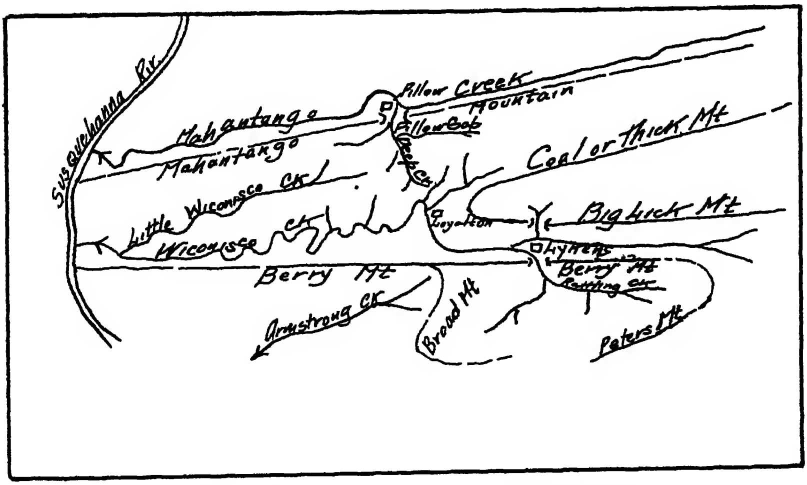

FIG. 142.—The drainage as it appears at present. Note the sharp bend in Wiconisco Creek near Loyalton.

present. Other small creeks in the Appalachians occupy large notches. Some of them were doubtless originally larger, but have suffered by the encroachments of more powerful subsequents, which have robbed them of their tributaries. Small streams can cut large gaps, that is, deep ones and broad across the top. It is merely a question of how far the stream has to cut its channel before reaching base level. A notch, broad at the bottom, can be cut only by a large stream, unless the bottom of the gap is close to base level, in which case a small stream may widen it by swinging laterally. The bottom of Pillow Gap is not at base level and hence another explanation is necessary. A possible explanation of the drainage changes can be hazarded. About two miles north of the town of Loyalton, Wiconisco Creek makes a right-angled bend, and the question arises why the stream does not continue up the broader valley between Mahantango and Coal or Thick mountains. Instead it extends east through Lyken's Valley between Big Lick and Berry mountains. The writer suggests that the portion of the stream south of the bend between Berry and Big Lick mountains once continued northward through Pillow Gap. Later Wiconisco Creek worked headward, beheading the stream at or near the point of the right-angled bend, producing an elbow of capture (Fig. 142). Deep Creek, the shrunken, beheaded remnant of the stream, is small and getting smaller, because its drainage basin has been encroached upon by the more powerful subsequent Wiconisco Creek, which is not handicapped by cutting across a hard rock ridge. Since the piracy which produced the numerous wind gaps took place during the period following the uplift of the Schooley (Kittatinny) peneplane and before the completion of the Harrisburg peneplane, it appears that the beheading of Deep Creek occurred during the Harrisburg cycle. The stream later suffered further shrinkage as a result of the constant encroachment of Wiconisco Creek, making the stream a misfit.

Klingerstown Water Gap

At a point about five and one-half miles east of the gap at Pillow, Pine Creek has cut a deep, narrow cleft in Mahantango Mountain (Fig. 143).

Outcrops of the Pocono sandstone, which is quite slabby here, give a dip of from about 55° to 60° to the south. The notch is approximately 860 feet deep, a figure representing the distance from the ridge crest on the west side to the bottom. Across the top the gap is a little less

FIG. 143.—Klingerstown Gap as seen from the south at a slight angle.

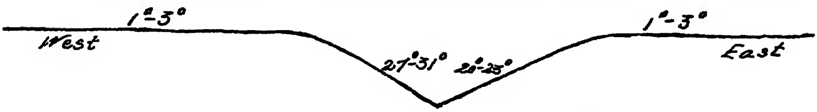

FIG. 144.—Profile of the Klingerstown Gap from a point directly in line and to the south. Horizontal and vertical scales about 2100 feet to the inch.

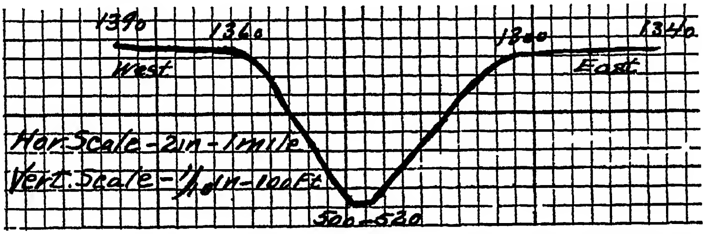

FIG. 145.—Profile of the Klingerstown Gap, taken from the topographic map.

than three-quarters of a mile wide, whereas at the bottom it is narrow, possibly 400 to 500 feet.

Klingerstown Gap has the characteristic features of a water gap, such as steep, straight or slightly convex slopes and V-shape and abrupt angles where the sides meet the ridge crest.

The east side of the notch has the lowest angle of slope, 20° to 23°, whereas on the west it reaches 27° to 31°, perhaps due to the greater scour by the stream on the west side at some time during the past (Fig. 144).

No facets appear in the profile; in fact, few gaps have straighter, smoother sides. The Pocono sandstone beds are unequally resistant to erosion, but the angle of dip (60°) is too high for the production of structural facets.

On both sides of the notch the ridge crest slopes at very low angles up to 3° toward the gap. These slopes are significant, for they indicate that the stream on the Schooley (Kittatinny) peneplane, coincident with Pine

Creek, existed during the Schooley (Kittatinny) cycle and that therefore superposition could not have occurred on that surface but must have taken place on a still older one.

It appears that Pine Creek was a tributary to Mahantango Creek, a subsequent stream on the Schooley (Kittatinny) peneplane. There is also the possibility that Mahantango Creek developed later, after the Schooley (Kittatinny) surface was uplifted. If that is the case, Pine Creek extended northward and may have flowed directly into the Susquehanna River. The position of Wiconisco and Mahantango creeks is such as to attract one's attention. Both streams occupy a position just north of and against the ridges instead of a central one in the valleys. The structure of the formations is that of a syncline and the beds in Mahantango Mountain dip 50° to 60° to the south. It may be contended that Mahantango Creek shifted its position down the dip of the formations against the hard, resistant Pocono ridge. However, the argument does not hold good for Wiconisco Creek, as the formations dip north at Berry Mountain. Although it is extremely doubtful, the writer suggests that their position possibly may be due in part to the tilting of the land to the southeast, crowding them against the hard rock ridges, and thus preventing further migration.

Among the interesting features of Wiconisco Creek are the striking, entrenched meanders in its course. Mahantango, Mahanoy, Shickshinny, Conodoguinet and many other streams in the Northern Appalachians exhibit the same feature. It is probable that the meanders were acquired by those streams during the development of the Harrisburg surface and are proof for the wide-spread existence of a fluvial base level. The narrow valleys cut by those streams below the level of the peneplane are often quite deep, in the case of Mahantango and Wiconisco creeks at least 100 feet.

A rather striking feature of Mahantango Creek is presented by the large loops which occur at the villages of Pitlow and Klingerstown, where the streams issue from the notches in the ridge. Both of the bends occur in the same position, on the left of the stream as it leaves the gap. A possible explanation is that Deep and Pine creeks carried alluvial material which was deposited where they emptied into the Mahantango. This material was laid down on the inside of the bends, causing the streams to cut on the outside of the curve, thereby migrating in that direction. Both streams have considerable velocity as they leave the gaps, which causes them to take a straight course for some distance before turning

to the left to enter the Mahantango. If the above theory is true, the rounded, pillow-like, slip-off slopes on the inside of the loops may be composed of alluvial material, provided that such deposits have not been removed by later erosion.

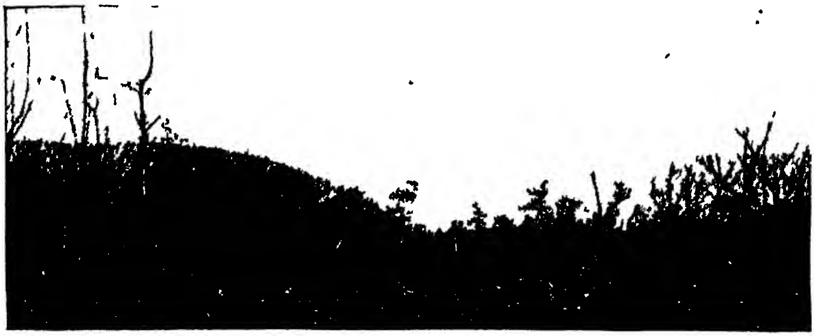

FIG. 146.—Kohler's Gap from Big Lick Mountain. View from the south.

FIG. 147.—Another view of Kohler's Gap from Big Lick Mountain.

FIG. 148.—Profile of Kohler's Gap from Big Lick Mountain, taken from the photograph above. Angles obtained in the field at a point directly in line with the gap.

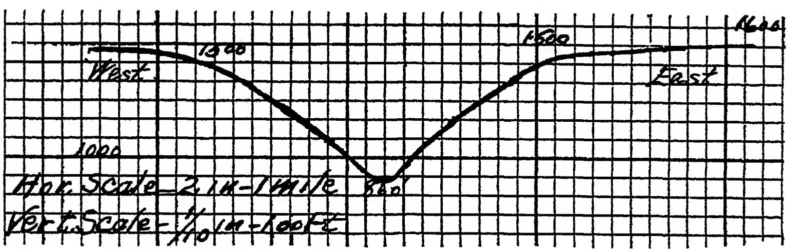

FIG. 149.—Profile of Kohler's Gap, taken from the topographic map.

Kohler's Water Gap

Kohler's Gap is located about one and one-half miles directly north of Tower City, where Rausch Creek, a tributary of Pine Creek, has cut a notch in Bear Mountain (Fig. 146).

Bear Mountain, another name for Coal or Thick Mountain, is composed of the Pottsville conglomerate. It has a dip of 40° to 50° to the south toward the axis of the narrow syncline, which pitches to the east.

Across the top Kohler's Gap measures about seven-eighths of a mile, whereas the bottom is narrow. The depth is approximately 640 feet, its elevation being 860 feet A. T. at the bottom; on the ridge crest the elevation is 1500 feet A. T.

The form of Kohler's Gap is very symmetrical, both sides having nearly the same angle of slope. At the bottom of the notch the maximum angle on both sides is 30°, grading by continuously convex slopes into the ridge crest, which is inclined at a low angle toward the gap (Fig. 148).

No facets appear in the profile and the sides are free from irregularities. The high degree of dip and the homogeneity of the thick-bedded Pottsville conglomerate prevent the formation of structural facets. Occasional rock outcrops are visible here and there and thick accumulations of debris, so common in wind gaps, appear to be absent.

The long slopes on the ridge crests, beginning at some distance back from the gap, indicate an older surface, below which the notch has been cut. On the top of Big Lick and Bear mountains this surface in some places is broad, gently undulating and nearly flat, clearly a peneplane which bevels the structure. It is obvious that the slopes on the ridge crest represent the Schooley (Kittatinny) peneplane and that such slopes are evidence against superposition of the Kohler's Gap stream upon the Schooley (Kittatinny) surface. It would seem that the stream was already there during the Schooley (Kittatinny) cycle. Superposition must therefore have occurred on a peneplane earlier than the Schooley (Kittatinny).

Water Gaps at Ashland

Near the mining towns of Ashland and Locustdale, Mahanoy Creek and one of its tributaries have cut two gaps in Mahanoy and Ashland Mountain (Figs. 150 and 153).

The rock formations consist of the Pottsville conglomerate and the coal measures. Mahanoy and Ashland Mountain, one ridge with two

FIG. 150.—Gap cut by Mahanoy Creek through Ashland Mountain. View from a point directly north of the gap.

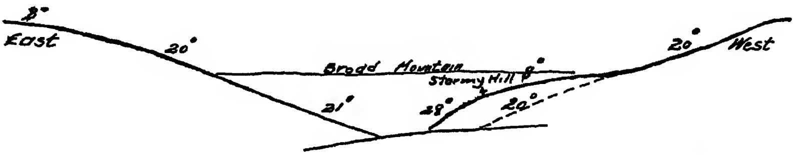

FIG. 151.—Profile of Ashland Gap, taken from the photograph above. Angles measured in the field from a point directly in line.

FIG. 152.—Ashland Gap as seen from a point to the northeast.

names, is composed of the Pottsville conglomerate, which has a dip of about 35° or 40° to the north, as measured on outcrops in Ashland Gap. Across the valley on Locust Mountain, north of Ashland and Locustdale, the dip is to the south. The dip of the sandstone at points north of Ashland and Locustdale is from 35° to 45°. The structure is that of a narrow syncline, extending in a southwest-northeast direction.

The gap at Ashland through which flows Mahanoy Creek has a width across the top of about five-eighths of a mile, whereas at the bottom it is quite narrow, roughly several hundred feet. The depth of the gap measured from the ridge crest, which has an elevation of 1560 feet A. T. on the west side, to the bottom of the gap at 840 feet A. T., is 720 feet, the distance below the Schooley (Kittatinny) peneplane.

The profile of Ashland Gap, seen from a point directly in line with it on Locust Mountain, displays what appears to be a great hollow or concavity on its west side. A walk through the notch or a study of the topographic map reveals a great bend in Mahanoy Creek where it

FIG. 153.—Locust Dale Gap from Locust Mountain across the valley to the north.

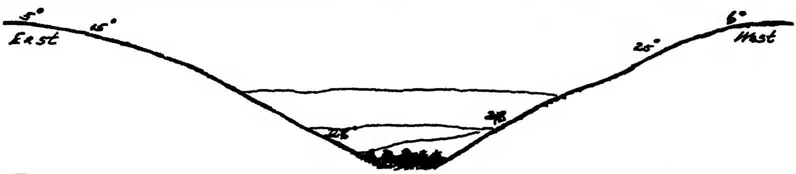

FIG. 154.—Profile of the Locust Dale Gap from the north, showing angles of slope. From a point directly in line with the gap. Hor. scale-1 in.—700 feet. Vert. scale-1 in.—850 feet.

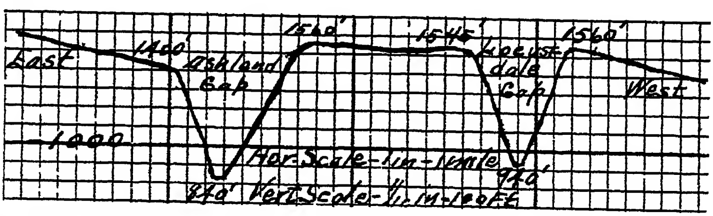

FIG. 155.—Profile of the Ashland and Locust Dale gaps, taken from the topographic map.

crosses the ridge. It flows parallel to the mountain and then turns abruptly to the south at the gap, flowing in a curved course through it, and on leaving it makes another turn to the west. On the outside of the bend the stream has produced a concave, undercut slope and has lowered the elevation of the ridge, forming the long, curved projection upon which part of Ashland lies. This elongate, rounded projection, called Stormy Hill, slopes in a northwesterly direction from the mountain and hides the west side of the gap from the observer viewing it from a point directly north and in line with it (Fig. 151).

Seen from Stormy Hill, the west side of Ashland Gap appears to be nearly as straight as the east side; in fact, the profile taken from the topographic map (Fig. 155) reveals no irregularities. The elevation of Stormy Hill where it appears to have its least slope, is from 1000 to 1100 feet A. T., approximately the elevation of the Harrisburg peneplane in this vicinity. A possible explanation for the elevation of the ridge crest on the east side is that the ridge has been narrowed on the inside of the bend in Mahanoy Creek, thereby lowering it to some extent. The slopes of Ashland Gap average about 20° and make rather abrupt angles with the ridge crest, which appears to slope at low angles toward the notch. Little debris occurs on the sides and rock outcrops are exposed in places.

Locust Dale Gap is occupied by a branch of Mahanoy Creek and flows south through the notch, meeting the main stream about a mile south. The formations in this gap dip north at an angle of approximately 35° to 40°. At the top the notch is about one-half mile wide; at the bottom it is narrow, there being little space in addition to that occupied by the width of the stream, the highway and the railroad. On the east side of the gap the maximum angle of inclination at the bottom is about 26°, decreasing to one of 15° or less near the top, grading from one angle to the other by a continuously convex slope (Fig. 154). On the west side the angle changes at a point about midway between the crest and the bottom. A concealed ledge of rock accounts for this slight irregularity and is to be expected when the low angle of dip of the formations is taken into consideration. The change in slope on the west side cannot be interpreted as a facet produced during a period of peneplanation, but is a structural facet.

The sides of Locust Dale Gap meet the ridge crest at rather abrupt rounded angles. On both sides the ridge crests is inclined toward the notch, and the slopes are very short. Ashland and Locust Dale gaps

exhibit no features other than those common to all water gaps, such as V-shaped, straight or convex sides, which meet the ridge crest at abrupt rounded angles, a paucity of debris and occasional prominent rock outcrops.

Water Gaps at Shamokin

Shamokin Creek passes through two deep gaps where it crosses Little and Big mountains, at points a short distance north of the city of Shamo-

FIG. 156.—Shamokin Gap in Big Mountain. View from a point south of the city of Shamokin.

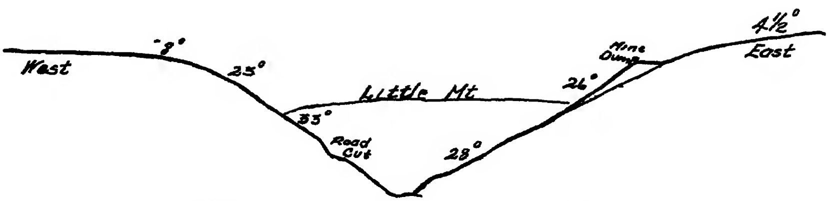

FIG. 157.—Profile of Shamokin Gap, taken from the photograph above Angles measured in the field at the same point from which the photograph was taken.

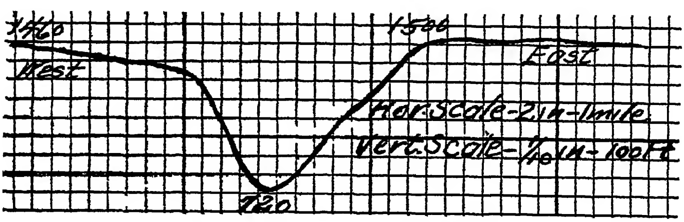

FIG 158—Profile of Shamokin Gap, taken from the topographic map

kin (Figs. 156 and 159). The notch in Big Mountain near the city may be called Shamokin Gap for convenience, while the other through Little Mountain may be referred to as the Weigh Scale Gap.

The structure of the formations is that of a syncline, the axis of which pitches to the east. This basin is surrounded on the north, west and south by two ridges. The inner ridge—Big Mountain on the north and Mahanoy Mountain on the south—is composed of the Pottsville conglomerate. The outer ridge—Little Mountain to the north and Line Mountain to the south—consists of Pocono sandstone. At Weigh Scale Gap the sandstone dips about 40° to 45° to the south, and in Shamokin Gap the conglomerate dips about 42° in the same direction.

Shamokin Gap has an elevation of 720 feet A. T. and is approximately 780 feet deep, the distance below the Schooley (Kittatinny) peneplane, which has an elevation of 1500 feet A. T. on the ridge crest at the east side of the gap. The notch is V-shaped, narrow at the bottom and about three-quarters of a mile wide across the top.

Weigh Scale Gap stands 660 to 680 feet A. T., about 800 feet below the ridge crest on the west side. It is quite narrow at the bottom and is seven-eighths of a mile wide at the top.

From the south (Fig. 157) the east side of Shamokin Gap appears to be almost straight, sloping at an angle of about 26° to 28°. On the west side the slope is fairly straight and has an angle of 33°, decreasing to some extent near the ridge crest. No facets appear in the profile of the notch, the sides being nearly straight. The ridge crest slopes toward the gap, on the east at an angle of from 3° to 5° and on the west at about 8° near the gap, but decreasing to one of from but 2° to 3° farther back.

Seen from a point to the south, Weigh Scale Gap has a profile that resembles that of Ashland Gap; the same conditions exist and the results are similar. The direction taken by Shamokin Creek across the ridge has produced a long, narrow projection, the elevation of which is lower than that of the ridge farther east, where it widens out. In other words the ridge is lower where Shamokin Creek makes the bend upon entering the gap, because it has been narrowed. All other conditions being equal, the elevation of a tilted formation which is being eroded will be inversely proportional to its thickness.

In the lower part of the notch the slope of the east side is about 28°, but this angle changes abruptly farther up, flattening out for some distance and ultimately reaching an angle of 17° (Fig. 160). The west side is nearly straight, the angle of slope being approximately 25° to 26°.

FIG. 159.—Weigh Scale Gap in Little Mountain. View from a point about one mile south.

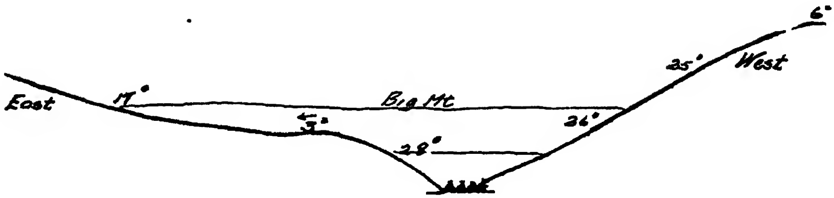

FIG. 160.—Profile of Weigh Scale Gap. taken from the photograph above. Angles measured in the field at a point directly in line with the gap.

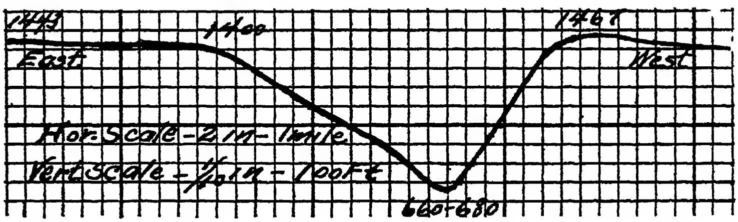

FIG. 161.—Profile of Weigh Scale Gap, taken from the topographic map.

The ridge crest of Weigh Scale Gap meets the sides of the notch at abrupt rounded angles, and slopes on the east at an angle of 6° and on the west side at an angle of from 3° to 5° toward the gap. No structural facets appear in the profile of Weigh Scale Gap, nor are there any which might be attributed to peneplanation.

Shamokin and Weigh Scale gaps exhibit the characteristics of all the water gaps in the Appalachians, such as the V-shape, the slope of the ridge crest toward the gaps, the abrupt rounded angles where the sides meet the ridge crest and the presence of numerous rock outcrops on the slopes. The significance of such features has been pointed out in previous discussions.

Mainville Water Gap

About five miles northeast of the town of Catawissa and near Mainville, Catawissa Creek has cut a notch in Nescopeck Mountain (Fig. 162).

Nescopeck and Catawissa mountains are ridges of Pocono sandstone which can be traced continuously into the Pocono ridges to the south. They form the north and south limbs of a syncline, the axis of which pitches to the east. The point where the two mountains meet rises abruptly from the Susquehanna valley and has an elevation of 1825 feet A. T., constituting one of the highest points in eastern Pennsylvania. The dip of the Pocono sandstone in Nescopeck Mountain, measured in Mainville Gap, is about 42° to the south, which causes the notch to narrow down from north to south; such narrowing occurs in all the gaps where the formations dip at angles sufficiently low. In Blue Mountain, in the places where the Shawangunk conglomerate stands at a high angle or nearly vertical, the narrowing of the gaps in the direction of dip does not take place or is not pronounced.

Mainville Gap is V-shaped, narrow at the bottom and about one-half mile wide at the top. The elevation of the bottom ranges from 540 to 560 feet A. T., and is about 750 feet below the ridge crest on the west side. On the east side the angle of slope is about 25°, whereas on the west the angle below is approximately 30°, grading by a convex slope upward. The elevation of the ridge crest is somewhat lower on the east side, the result of the course of Catawissa Creek through the gap. As it enters Mainville Gap, it makes a sharp bend, narrowing the ridge in a manner similar to that at Shamokin and Ashland gaps.

The slopes of Mainville Gap appear to have no facets, although the photograph (Fig. 162) displays what seems to be an angularity on the west side. This irregularity is not so conspicuous when the view is directly through the gap (Fig. 163). A low angle of dip of the sandstones would favor the production of structural facets.

The ridge crest slopes at low angles, from 2° to 4° toward the gap, and makes abrupt angles with the sides. Such sharp angles, V-shape, straight,

FIG. 162 —Gap cut by Catawissa Creek through Nescopeck Mountain near the town of Mainville View from a point a short distance north of the gap

FIG 163.—Profile of Mainville Gap, taken from the photograph (Fig. 162). Angles obtained in the field from a point directly in line.

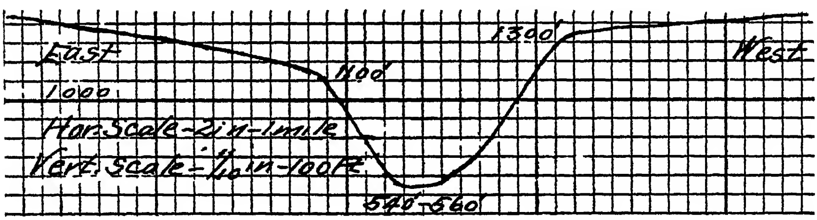

FIG. 164 —Profile of Mainville Gap, taken from the topographic map.

steep sides, a paucity of debris and numerous rock outcrops are the result of constant refreshing of the sides by erosion.

The slope of the ridge crest toward the notch can mean only one thing: the Schooley (Kittatinny) peneplane must have been inclined toward Catawissa Creek, the stream on the upper surface coincident with the present one, signifying that the creek was not superposed on the Schooley (Kittatinny) peneplane but necessarily upon a still older one.

Nescopeck Water Gap

Four miles southeast of the town of Berwick, Nescopeck Creek has cut a deep cleft through Nescopeck Mountain (Fig. 165).

This ridge is composed of the hard, resistant Pocono sandstone, which dips at an angle of only 30° to the south, measured at an outcrop in the railroad cut near the gap.

The bottom of the notch stands 680 feet above sea-level, approximately 840 feet below the ridge crest, the elevation of which reaches 1500 feet A. T. on the east side. Across the top the distance is three-quarters of a

FIG. 165—Gap cut by Nescopeck Creek through Nescopeck Mountain. View from a point about one mile north of the gap

FIG. 166.—Profile of Nescopeck Gap, showing angles of slope. From a point directly in line and to the north of the gap. Hor. scale 1 in—1075 feet. Vert. scale 1 in—1125 feet.

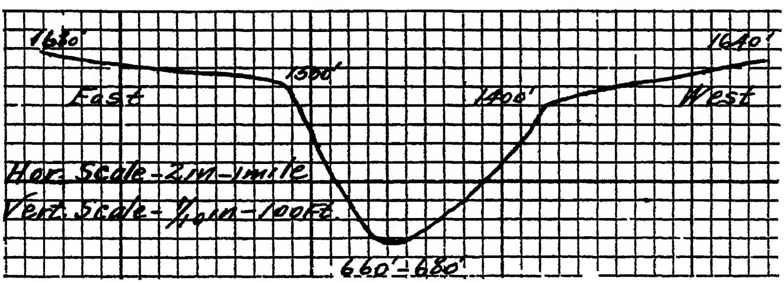

FIG. 167.—Profile of Nescopeck Gap, taken from the topographic map.

mile—not great considering its depth. It is a narrow gap compared with other notches in the Appalachians.

Viewed from the north (Fig. 166), the east side appears to be concave and has a slope of about 26° near the bottom and somewhat more farther up near the ridge crest. On the west the slope is more convex, having an angle of about 30° near the bottom and one of 13° farther up. About midway on this side there appears to be an abrupt change of slope, due to an irregularity in the resistance of the beds to erosion; a rock ledge produces an angularity in the profile. In view of the fact that the formations consist of alternating beds of sandstone and shale, and the dip is as low as 30°, one would expect structural facets to occur. Hence there are no facets which can be interpreted as due to peneplanation during long halts in the uplift of the land.

The ridge crest slopes at angles of about 3° on the west side and 5° on the east, meeting the sides of the gap at rather sharp angles (Fig. 166).

Nescopeck Creek presents a fine example of entrenched meanders throughout its entire course. The portion showing this feature to best advantage is that from Nescopeck Gap to the point where the creek enters the Susquehanna River. Excellent slip-off and undercut slopes are present in this section of the creek. The Pennsylvania Railroad crosses five sizable bridges in this short distance, due to the large and numerous bends in Nescopeck Creek.

Shickshinny Water Gap

Near the town of Shickshinny a notch has been cut through Shickshinny Mountain by a creek of the same name (Fig. 170).

The ridge is composed of the Pocono sandstone, which dips at the low angle of 20° toward the southeast. Outcrops of sandstone are numerous within the notch, and the formation appears to be a thick-bedded sandstone with hard and soft beds alternating. The structure of the formations is that of a narrow syncline, Huntington and Lee mountains uniting to form the apex, Knot Mountain, which rises abruptly from the valley of Fishing Creek at Orangeville.

Shickshinny Gap is more than a mile long, seven-eighths of a mile wide across the top and several hundred feet wide at the bottom. The elevation of its floor ranges from 580 to 600 feet A. T. about 900 feet below the ridge crest on the east side, where the elevation attains 1520 feet A. T. From a point directly north of the gap the sides appear to have a rather high angle of slope, 27° being the maximum. On the west

FIG 168.—Looking south through Nescopeck Gap

FIG. 169.—Nescopeck Creek in Nescopeck Gap.

side the slope decreases from 27° below to 15° near the point where the ridge crest meets the gap, grading by a continuously convex slope from one angle to the other (Fig. 171). On the east side two changes of slope occur where ledges of rock outcrop. One of the outcrops is located near the bottom of the gap and the other midway between the bottom and the ridge crest. The lower half of the east side slopes at an angle of about

FIG. 170.—Shickshinny Gap from the north.

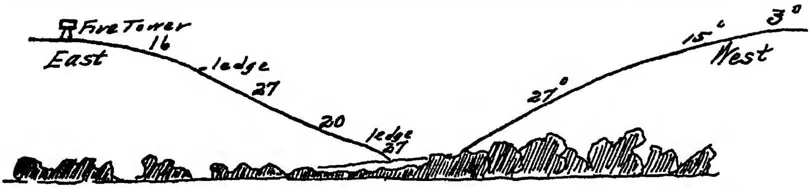

FIG. 171.—Profile of Shickshinny Gap, showing angles of slope. From a point directly in line and to the north of the gap. Hor scale-1 in —1300 feet. Vert. scale-1 in. - -1080 feet.

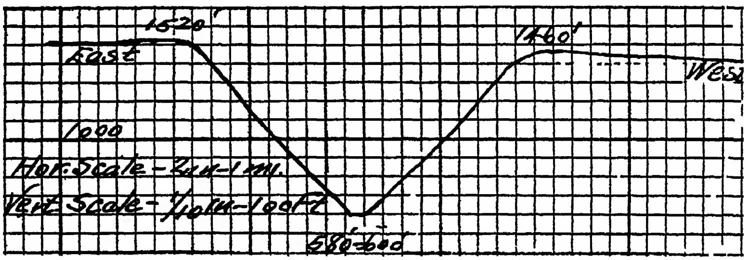

FIG. 172.—Profile of Shickshinny Gap, taken from the topographic map.

27°, while above the upper ledge the angle of slope is only 16°. The low angle of dip, 20°, of the Pocono sandstone and the alternating series of hard and soft strata are favorable for the development of structural facets.

In Shickshinny Gap the constant refreshing of the slopes by erosion, a process which does not occur in the wind gaps, produces the features found in all water gaps and already noted several times.

The ridge crest on both sides of the notch is broken by sags, a few of which are shallow wind gaps. The slopes toward the gap are very short

ones, but sufficiently long to indicate that the land sloped toward the stream on the Schooley (Kittatinny) peneplane.

Evidences of glaciation occur in Shickshinny Gap, for on the bottom of the notch along the paved highway are great deposits of material. This material appears to be fluvio-glacial in some places, while in others it resembles glacial till. Much of it is poorly assorted, water-worn material, occurring in thick deposits as high as 100 feet above the level of Shickshinny Creek, ending abruptly at some distance from the base of the mountain. At the point where the three branches of Shickshinny Creek meet near the north entrance of the gap, there is a broad flat, composed of gravel and fluvio-glacial material, which stands well above the level of Shickshinny Creek. Evidences of scour by the ice in the gap, such as striæ, chattermarks, grooves and so forth are absent. On the ridge crest at the fire tower on the east side of the notch there appears to be little evidence of glaciation. Proof that the gap was widened or deepened by ice action seems to be lacking. Possibly the ice had little effect due to its thinness near the edge of the ice sheet. The map accompanying the Report of Progress Z, second Geological Survey of Pennsylvania, reveals that the terminal moraine passes over the syncline at a point several miles south of Shickshinny Gap, indicating that the notch had been glaciated. The fact that Culver, Delaware and Shickshinny gaps all display very prominent rock ledges and outcrops is perhaps due to the passage of the ice through the notches, removing much of the talus which covered the rock ledges.

Conclusions

Profiles drawn by the author along the ridge crests in eastern Pennsylvania seem to indicate but one peneplane, the Schooley (Kittatinny). The higher points on the ridge crests mark the former divides between the streams on the upper surface and therefore do not represent remnants of an older, higher peneplane. There appears to be no evidence of a peneplane lower than the Kittatinny in the ridge and valley section of eastern Pennsylvania that can be correlated with the Schooley surface, and none higher than the Schooley peneplane on South Mountain that can be correlated with the Kittatinny surface. Hence it seems quite conclusive to the writer that they are one and the same surface, which has been unequally warped and possibly faulted by uplift.

The theory that wind gaps occur at certain elevations which mark fluvial base levels is not supported by the evidence obtained from profile and field studies of the ridges in eastern Pennsylvania. If the eleva-

tions of all pronounced notches (a few of which may belong to the class of cols) be examined, we find that their altitudes vary from 720 to 1700 feet A. T. When the notches which are clearly wind gaps are studied, the evidence is equally conclusive. Their elevations vary from 720 to 1640 feet A. T. and it is obvious that no accordance of their levels exists. The curve of irregularity (Fig. 2) for wind gaps illustrates graphically the extent of the variation in their altitudes.

The water gaps in the same area vary in elevation from 280 to 1160 feet A. T. and it is obvious that there is no accordance in their altitudes, as indicated by the curve of irregularity (Fig. 2). The elevations of the wind gaps are more variable than those of the water gaps. Since the latter do not represent any peneplane level, there would seem to be some doubt as to the value of wind gaps as indicators of former peneplane levels.

The only wind gap which occurs at, or only slightly above, the Harrisburg level is Culver's Gap. As it was undoubtedly deepened somewhat by glaciation, we cannot be certain of its altitude before the glacial period. The other wind gaps vary in elevation from 100 to 870 feet above the Harrisburg level, only three having elevations approximately in accord with one another. It is clear that there is no accordance in wind gap elevations when the altitudes of the wind gaps above the Harrisburg peneplane are considered. Nor is there any accordance in wind gap or water gap elevations when their depths below the Schooley (Kittatinny) peneplane are compared.

If the wind gaps and water gaps in Blue Mountain alone are tabulated, similar disparity is noted. The wind gap elevations vary from 860 to 1580 feet A. T. and the water gaps from 280 to 560 feet A. T. There is greater variation in the elevation of the wind gaps than of the water gaps. According to Barrell's theory, wind gaps, which are supposed to record a peneplane level, should be more uniform in altitude than are the water gaps in the mature stage of the current cycle. Since the water gaps of today have varying elevations and are known not to represent a peneplane level, the still more irregular wind gaps cannot be regarded as reliable evidence of former peneplane levels.

Barrell would apparently correlate the slopes of Pen Argyl Wind Gap with the upper slopes of the Delaware Water Gap and other water gaps. He seems to think that these slopes are more gentle because they belong to an earlier cycle of erosion in which all gap slopes were gentle. The evidence shows that the slopes of all the wind gaps are gentler than the upper slopes of the Delaware and other water gaps, because the slopes

of the latter have been determined by vigorous erosion in the present cycle, with the result that rock ledges are the controlling factor. In the case of the wind gaps, on the other hand, the slopes are determined by weathering that has taken place since an earlier cycle. It seems probable that, when capture occurred, the notch of the wind gaps was as steep as that of the present water gaps and that the difference in the angle of slope is due to the abandonment of the wind gaps to weathering.

The angle of slope of the water gaps is much steeper than that of the wind gaps. The figures obtained by the writer, by taking an average for all water gaps and for all wind gaps in eastern Pennsylvania, give $26\frac{1}{2}°$ for the water gaps and $14\frac{1}{2}°$ for the wind gaps. The water gaps are without exception V-shaped, whereas the wind gaps usually have broad, nearly flat or rounded bottoms and gentler slopes. Since the abandonment of the wind gaps to weathering, after piracy occurred, their sides have become more gentle and their bottoms broadly rounded, due to the accumulation of debris which has worked its way down the slopes. On the whole, conspicuous rock ledges are much more common in water gaps than in wind gaps and the thick talus deposits which tend to cover the ledges in the wind gaps are less abundant in the water gaps. This is clearly the result of continual refreshing of the slopes of the water gaps by stream erosion.

Barrell believed that the form of the wind and water gaps might give valuable evidence as to the nature of erosion cycles. He was of the opinion that the facets in their profiles are indicative of still stands of the land, during which peneplanation took place. The present writer believes that the facets are the result of unequal resistance of hard rock beds to erosion. Where there are alternating layers of hard and soft rock which stand at an angle sufficiently low, rock ledges produce facets. As a rule the more resistant beds project into the gaps, whereas the softer beds weather down to gentler slopes. Where the beds stand at high angles, facets are absent. At Van Nest Gap the rock is a homogeneous gneiss which weathers uniformly, and therefore facets are not present in its outline. The only water gaps that have angularities in their profiles that can be interpreted as facets are the Lehigh, Delaware, Nescopeck, Shickshinny and possibly the Mainville notches. In all of these cases there are alternating beds of hard and soft rock dipping at angles sufficiently low to produce facets. At all the rest of the water gaps the dip of the beds is above 40° and in all but a few cases above 55°. Here facets are lacking. The evidence thus seems to be strongly against the theory that the facets

are indicators of fluvial base levels. The false facets, which are present in some of the gaps, are due to local narrowing of the ridges, either on the outside of the bend of a stream or through the dissection of the ridge longitudinally by small streams. Such is the case at Schuylkill Gap, at the notches cut by the Susquehanna River through Blue Mountain and Mahantango Mountain, and at the Weigh Scale, Ashland and Manada gaps. Pseudo-facets are absent where the ridges have not been narrowed by erosion.

The accumulation of debris on the slopes of the wind gaps, no doubt has concealed rock ledges which were prominent when they were water gaps, since the tendency would be for the slopes to become graded, giving a smooth outline, without facets. Where one side of a gap is steeper than the other, it is clear that greater erosion by the stream took place on that side. This is usually the case when the stream takes a curved course across the ridge; the undercut slope on the outside of the bend would be the steeper.

In the majority of cases it was found, as a result of profile and field studies of Appalachian ridges in Pennsylvania and New Jersey, that for long distances on either side of water gaps and major wind gaps, ridge crests representing the upper (Schooley or Kittatinny) peneplane descend faintly toward the major stream courses, indicating that these streams were superposed in a cycle earlier than the Schooley (Kittatinny) and held their courses throughout Schooley (Kittatinny) time. These faint slopes on the ridge crest, adjacent to wind gaps and water gaps, support the view that the Schooley peneplane and the Kittatinny peneplane are one and the same. The presence of high level, broad, shallow valleys on the Schooley (Kittatinny) peneplane, coincident with the present courses of the larger rivers, is not consistent with the theory that these streams were incised in this peneplane from an immediately overlying coastal plain cover. Thus the author's study of Appalachian profiles adjacent to wind gaps and water gaps has discovered an unexpected confirmation of the theory of Appalachian evolution advocated by Professor Johnson on the basis of profile studies in New England.*

* Douglas Johnson and Karl Ver Steeg: "Appalachian Studies." (Abstract.) Bull. Geol. Soc. America, Vol. XL, 131-133, 1929.

BIBLIOGRAPHY

BARRELL, JOSEPH

(*1*) 1920. Amer. Jour. Sciences, 4th Series, XLIX. pp. 227-258, 327-362, 407-428.

BASCOM, F. AND MILLER, B. L.

(*2*) 1920. Elkton-Wilmington Folio, Maryland, Delaware, New Jersey and Pennsylvania. Geologic Atlas, No. 211.

DAVIS, W. M.

(*3*) 1909. The Peneplain: Geographical Essays. Edited by D. W. Johnson, pp. 350-380.

KEITH ARTHUR

(*4*) 1894. U. S. Geol. Survey. 14th Annual Report. Pt. 2.

KNOPF, ELEANOR B.

(*5*) 1924. Bull. Geol. Soc. Amer., XXXV, pp. 633-668.

STOSE, GEORGE W.

(*6*) 1927. Bull. Geol. Soc. Am., XXXVIII, pp. 493-504.

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THE UTILIZATION OF HEXOSE CARBOHYDRATES BY LEPIDOPTEROUS LARVAE*

By F. MARTIN BROWN

CONTENTS

HISTORY AND INTRODUCTION

The processes of digestion that take place in phytophagous insects have not been studied thoroughly except perhaps in the case of the commercial silkworm *Bombyx mori* (Acgua, 1916), and the results of these few investigations seem to be conflicting. Acgua believes that in silkworms the proteins and soluble sugars of the mulberry constitute the principal food. Peligot (1867) accumulated data in a way similar to that herein described and came to the conclusion that the nitrogenous materials were the main source of food for silkworms. Hering (1926) expresses the opinion that carbohydrates are seldom utilized. This leaves the utilization of any particular type of food-stuff in need of considerable and extensive investigation.

For this study I selected a common, general-feeding lepidopterous larva, *Automeris io*. This species was chosen primarily because it is easily raised in the laboratory and the adults mate freely in captivity; secondarily, because the reactions to several foodplants could be studied in the same species or even in the same family of larvæ; and lastly, be-

* The publication of this paper has been made possible through a grant from the income of the John James Audubon Fund.

cause the larvæ are rather large and afford a copious supply of excreted materials in the later stages of their lives.

Since, however, a supply of the larvæ of *Automeris io* could not be had until early summer, the preliminary work of establishing methods was carried on with the larvæ of *Basilarchia archippus* as they emerged early in the spring from their hibernacula. These caterpillars feed on the leaves of the common willow, *Salix discolor*. In the main the methods used are those current for the analysis of plant tissues (Morrow, 1927). The pressure of many analyses made it necessary, however, to modify them to some extent. In order that these results may be compared with those obtained by other investigators and that others wishing to carry on similar studies may benefit by this work, I feel justified in including a rather lengthy description of the methods in the body of this paper. Chemists will see immediately that the results are by no means absolute totals of the materials investigated but rather amounts derived by identical repetition of the analyses and therefore comparable. Rather than make a hasty survey of all food-stuffs ingested, it was felt that a thorough survey of one group would net more worthwhile results, and with this in mind the hexose carbohydrates were selected, since they form one of the principal groups of food-stuffs in green plant tissue, and the extent of their utilization is apparently a matter of controversy.

THE GROUPS OF GLUCIDES FOUND IN PLANT TISSUE

Not more than fifty years ago it might have been said that all glucides* were of plant origin. Since that time the work of Emil Fischer, J. C. Irwin, C. S. Hudson and a multitude of others has added so greatly to our knowledge that the synthesis of many purely laboratory glucides has been brought about. It has been through this synthesis that most of our knowledge of the natural glucides and of their composition has been acquired. Today it is quite probable that the majority of known glucides are the product of the test tube rather than of the green leaf. By far the greater number of them are what may be called combined glucides, in which the carbohydrate molecule has been combined with one of an entirely different character.

The simple glucides with which we are concerned are classified according to the number of carbon and water molecules contained in them. They all respond to the formula $C_x\ (H_2O)_y$. When the subscript for C and for (H_2O) are the same, the compound is called a monosaccharide.

* An excellent text devoted to these compounds is "The Carbohydrates and Glucosides" by E. F. Armstrong.

Disaccharides have formulæ of the type C_x $(H_2O)x\text{-}1$; in this case two monosaccharides have combined with the loss of a molecule of water. The formation of a trisaccharide is similarly brought about by the loss of two water molecules, and so on. These polysaccharides are all reduced to monosaccharides by the addition of water molecules during hydrolysis. When the number of carbon atoms in the monosaccharide unit is six, the sugar is said to be a hexose sugar; when it is five, a pentose sugar. These two groups are the only ones that are commonly found in plant tissue and of them the rôle played by pentose sugars in animal metabolism is still to be determined. Perhaps one reason for this is that no simple technique has as yet been devised for the detection and estimation of such sugars. For the use of biologists such a method must be rapid and fool-proof. The present methods involve the rather difficult task of doing furfural distillations and determinations, and are too long and sensitive to error for general biological use. Another reason may be that what work has been done tends to indicate that the pentoses are not utilized by organisms other than bacteria. This is a field for much research.

Fortunately hexose sugars are rather easily detected and determined. This is due to the presence of ketone and aldehyde groups that have the power of reducing many compounds. The usual methods depend upon the reduction of alkaline copper solutions to copper oxide and the estimation of the quantity of precipitated oxide by gravimetric, volumetric, colorimetric or electric methods. Sugars capable of doing this are called reducing sugars. The lack of this power in the case of certain polysaccharides is due to the destruction of the ketone or aldehyde group in the union of the monosaccharide units. Upon hydrolysis these groups are restored and thus make the detection and the determination possible by the usual methods.

By taking advantage of the selective ability of certain enzymes and chemical means of hydrolysis, it is possible to get estimates of the quantity of various hexose carbohydrates present in a given sample with sufficient accuracy to be used for general biologic work. The most complex of these simple carbohydrates that may be found in plants are the starches, gums and cellulose with an empirical formula $(C_6\ H_{10}\ O_5)_X$, with X probably above thirty and possibly well over one hundred. These are hydrolyzed slowly and with difficulty, some only after drastic treatment that may not only hydrolyze them but wholly or partially decompose the products of hydrolysis.

The compound glucides formed in plant tissue are usually called glu-

cosides and are a multitude of compounds in which glucose or similar monosaccharides are in combination with other types of organic molecules. These are commonly divided into classes dependent upon the non-carbohydrate portion such as phenols, alcohols, aldehydes, anthocyans, oxycumarin derivatives, etc. Apparently the primary use of such compounds in plants is to render non-toxic many compounds that might have a detrimental effect upon the protoplasm of the cell. Many plant pigments, essential oils and drugs of commerce are the non-carbohydrate fractions of glucosides that have been hydrolyzed. Several that have been recognized in the plants used in these experiments are:

In willow (*Salix discolor*),
salicin-glucoside of ortho-oxy-benzyl-alcohol

salinigrin-glucoside of meta-oxy-benzaldehyde;

In wild cherry (*Prunus serotina*),
seratin-glucoside of 1:3:3':4'-tetra-hydroxy-flavenol

prunasin-glucoside of dextro-mandelonitrile.

Other similar glucose-yielding compounds may or may not be present. Tannins are glucosides but are not available for determination by the methods of analysis outlined.

Methods of Analysis

These carbohydrates may be separated into two principal groups, those readily soluble in water and those not so. The members of the first group are for the most part well known, those of the second less well known. In this study the separation was accomplished by the usual method of extracting the mass with eighty per cent alcohol on a water bath in a large Soxhlet type extractor; ten grams of leaf tissue or as much feces as were procurable, usually about a gram, constituted the charge. When all of the coloring matter had been extracted, it was considered that the soluble sugars, too, had passed into solution. This usually required up to twelve hours, so all extractions were run for that length of time in the final series. The alcoholic extract was then put into a Claissen flask and the alcohol was carefully distilled off under reduced pressure. When the residue in the flask reached about one-fifth of the original volume, one hundred milliliters of distilled water were added and the distillation again carried on until the volume had been reduced to one-fifth of the original. It was then considered to be free of alcohol. During this

process practically all of the waxes, oils, plant pigments and other alcohol-soluble, water-insoluble ingredients of the extract were precipitated. After cooling, these were removed by filtration, and the precipitate on the paper and in the flask recovered by redissolving it in methyl alcohol and evaporating it to dryness in a porcelain dish over a water bath. It was dried for five hours in a hot-air oven at 110° C, weighed and reported as "alcohol-soluble, water-insoluble portion."

The filtrate, or alcohol-soluble, water-soluble fraction, was treated with basic lead acetate to remove the dissolved nitrogenous materials, tannins, etc., and immediately after filtering, was treated with dry, powdered, disodium phosphate to remove the lead; it was then filtered and washed. The filtrate and wash water was made up to volume and either the reducing sugar content immediately determined or the filtrate preserved with a layer of xylene or toluene for later analysis. This reducing sugar content was reported as milligrams of "glucose" of Group One sugars per gram of substance used. The term "glucose" is employed here as a blanket term to cover all reducing sugars and the amount reported is necessarily not the true amount present, as different reducing sugars reduce copper compounds at different rates.

The non-reducing sugars were then hydrolyzed by bringing a measured portion of the water-soluble filtrate and an equal volume of twice normal sulphuric acid to a boil and allowing it to continue to boil for exactly sixty seconds. At the termination of the boiling period the beaker was plunged into cold water and after five minutes made exactly neutral to litmus by cautiously adding four times normal sodium hydroxide while stirring vigorously. The resulting solution was then made up to volume, its reducing sugar content determined and calculated to milligrams per gram of the original substance. This represents both Group One and Group Two. Group Two alone was determined by subtracting the value derived for Group One and was reported as "glucose." This completed the dissection of the soluble sugars.

The residue after alcoholic extraction was further treated by boiling in a sufficient quantity of distilled water for exactly twenty minutes. When it had cooled to about 37° C, 0.2 grams of Taka-diastase was added and thoroughly stirred through the mass. The material was then covered with a film of xylene and put into an incubator at 37° C to digest for twenty-four hours. At the end of that time the solution was filtered off and the wash water added to it and made up to volume. Care was taken to drain the residue as completely as possible of all liquid. The

reducing sugar was then determined and reported as Group Four in milligrams of "glucose" per gram of original substance. This group was comprised, theoretically, solely of starch. Blank tests run on the enzyme preparation showed some reduction of copper. The recorded "glucose" for this group has been corrected for this error. The uncertain constitution of the enzyme preparation made it impossible to compute the milligrams of starch represented by this amount of reduction.

Group Three is usually termed the "easily acid-hydrolyzable" portion. It was estimated by boiling the starch-free residue with sufficient normal sulphuric acid for exactly sixty seconds and allowing the beaker to stand on a wooden table for fifteen minutes before it was rapidly cooled and neutralized with four times normal sodium hydroxide. The hydrolysate was made up to volume, then analyzed for reducing sugars and the results expressed as "glucose." This completed the carbohydrate dissection.

The final residue was washed completely free of sulphate ions and dried in a hot-air oven for five hours at 110° C, weighed and reported as "residue" in terms of milligrams per gram of the original substance.

Method of Determining Amount of "Glucose"

Since it was necessary to make at least twelve sugar determinations a day in addition to preparing the solutions, a rapid and accurate method for small quantities of sugar was needed. The Folin-Wu method (Myers, 1924) for blood sugar was selected because of its sensitivity to small quantities. But, as all colorimetric methods are notoriously inaccurate when there is any considerable difference in concentration between the standard used and the unknown, it was felt that the amount of reduction should be measured by a method other than colorimetric. To this end, the dark blue solution obtained after the addition of the phospho-molybdic acid was bleached out by the use of a 0.005 normal solution potassium permanganate run in from a burette (adapted from Amick, 1928). Since this is a time reaction, great care was taken to finish each titration thirty seconds after starting it. The value of a milliliter of the permanganate solution was set each day by titrating a sample containing a known amount of glucose.

Conditions Affecting "Glucose" Content

In order to get comparable results it is imperative that the samples of leaves for food and analyses be taken from the same branches and in

the same stages of development (Maillot and Lambert, 1905). To this end only well developed leaves were selected and alternate leaves from a branch used for food and for analysis. Similarly it is necessary that the leaves be collected at the same hour each day (Kawase, 1918). A similar precaution must be taken in collecting the excreta. Unless this is done the continuous action of moulds that apparently begin to develop soon after the pellets have been voided will cause marked errors. The analyses in Table I show this well. A sample was collected at 9 A. M. on July 16 and represented the voided matter for the previous twenty-four hours. This was divided into two roughly equal amounts and one immediately boiled with 80% alcohol to prevent any further change in the sugars; the other was left under laboratory conditions until 9 A. M. on July 17 when it was treated with alcohol.

TABLE I

EFFECT OF DELAY UPON ANALYSIS OF FECES

Carbohydrate Groups	Analysis at time of collection vii–16–'30 mg. per g.	Analysis made one day after collection vii–17–'30 mg. per original g.	Differences mg. per original g.
One & Two..	16.8	27 0	+10 2
Three............	17 5	19 2	+ 1 7
Four.............	11.3	7 6	− 3 0
Water...........	259.3	192.9	−66 4

Cultures made from the surface of food leaves showed the presence of molds, yeasts and bacteria upon all specimens examined. Similar cultures made upon the materials in the intestines of six larvæ of *Automeris io* indicated that there is some bactericidal force either inherent in the caterpillar's digestive system or due to compounds released by digestion from the leaf tissue. Only two cultures yielded easily culturable micro-organisms. One was an aerobic spore-former, *Bacillus* sp.; the other a mold, *Aspergillus* sp. The mold grew profusely on the feces; in fact, that substrat proved to be the best medium for its culture. It is probably an important factor in the changes undergone by the carbohydrate content of the feces as indicated in Table I. In addition a part of the difference may be due to autolysis.

TABLE II

FOOD INGESTED: FECES EXCRETED RATIO

July	21	22	23	24	25	26	27	28	29	Aver.
Food ingested....................	1.389	0.830	0.484	1.159	0.804	0.813	1.096	1.658	1.635	....
Feces excreted..................	0.533	0.428	0.220	0.486	0.295	0.413	0.546	0.829	0.826	....
Food ingested per gram of feces...	2.6	2.0	2.2	2.4	2.7	2.0	2.0	2.0	2.0	2.2

DETERMINATION OF FOOD INGESTED: FECES EXCRETED RATIO

Ten *Automeris io* larvæ were confined separately in tightly stoppered shell vials. Each day they were fed weighed amounts of fresh wild cherry leaves and after twenty-four hours the residual leaves and feces were weighed. From these data Table II has been constructed in summary. These data average 2.2 grams of fresh leaves ingested for each gram of feces voided.

Because of the doubtful accuracy in determining the amount of food ingested to produce a given weight of feces by such direct methods for large quantities, it was decided that the ratio should be derived from the analytical data. This would be an easy and feasible method if it were known that any one constituent of the food was unaltered during the passage through the caterpillar. However, such a fraction was not known. But if a ratio between the amounts of "glucose" per gram of food and per gram of feces derived from that food for each group be determined, it may be assumed that the group showing the lowest ratio is the least affected. To illustrate, Table III was constructed from data relative to the larvæ of *Basilarchia archippus* feeding upon *Salix discolor* that had been gathered at 8 A. M., E. S. T., May 16, 1929.

TABLE III

ANALYSES OF FOOD AND FECES OF *B. archippus* ON *S. discolor*

	In fresh leaves mg. per g.	In feces mg. per g.	mg. per g. in leaves / mg. per g. in feces	% "utilized"
Group I......	5.5	1.7	3.24	82%
Group II.....	22.0	1.2	18.33	97%
Group III.....	4.3	7.3	.59	0%
Group IV.....	22.6	38.7	.59	0%
Water........	671.	496.	1.35	44%

From this it is apparent that Group Three and the starch Group Four had not been digested or at least were utilized to a far less degree than the rest of the glucides observed. If we suppose that the starch was not utilized, then each gram of feces represented 38.7, 22.6 or 1.7 grams of fresh leaves. Similarly the amount of food ingested per gram of feces voided by *Automeris io* based upon starch for five consecutive days is given in Table IV.

TABLE IV

COMPUTED FOOD INGESTED: FECES VOIDED AND RELATIVE HUMIDITY

July	23	24	25	26	27
Relative humidity.....	65–70%	60–70%	85–90%	90–92%	65–85%
Food ingested/Feces...	4.5	4.6	2.7	2.1	3.6

Inasmuch as the data in Table II was accumulated from larvæ in individual vials kept tightly stoppered, it may be assumed that the relative humidity in the case of Table II was between 90% and 100%. The single observation from Table IV under similar conditions of humidity shows perfect agreement with the data of Table II, and the remaining observations in Table IV are at least inclined to support rather than refute this. So we may assume that the method of establishing the ratio between the food ingested and the feces voided from analyses of both is valid.

Selection of the Food Plant for Final Analyses

When the eggs of *Automeris io* began to hatch in late June, groups of from thirty to fifty larvæ were fed upon different plants and were fed solely upon those throughout their lives. The plants used were *Prunus serotina, Quercus alba, Quercus velutina, Acer rubrum* and *Hicoria alba.** Typical carbohydrate analyses of samples of leaves of each of these are given in Table V; the figures are milligrams per gram of original substance.

Table V

Typical Analyses of Food Leaves

milligrams per gram of tissue

	Q. alba	*Q. velutina*	*A. rubrum*	*P. serotina*
Water..................	600.	740.	695.	667.
Group I................	11.5	9.6	3.9	3.5
Group II...............	nil.	nil.	2.5	9.9
Group III..............	nil.	1.3	1.7	4.3
Group IV...............	8.2	6.2	8.0	9.3
Chlorophyll, etc.........	37.0	31.8	33.4	40.2
Calories per g...........	2,200	3,500	2,800	4,580

Inasmuch as all of these trees were growing in an area not more than one hundred feet square on an exposed slope, and since the leaves in this series of analyses were collected at the same time on the same day, several points of interest may be noted, namely, the comparative dryness of the white oak leaves, the marked amount of Group Three compounds in the wild cherry and the absence of Group Two compounds in the oaks when analyzed by the foregoing methods. The calorimetric determinations were made by Mr. Richard G. Burlingame, using a Parr Peroxide Bomb calorimeter, and the figures quoted are averages of several determinations on each sample. In all, during the summer more than sixty measurements were made of the calorific value of the various samples used for food.

* According to "The Illustrated Flora of the Northern States and Canada" by Britton and Brown, first edition, 1897.

It soon became apparent that the larvæ feeding upon wild cherry and black oak were growing more rapidly than the others. Of these two, the wild cherry was selected for the final set of analyses. Table VI shows in graphic form the rate of development of larvæ feeding upon these five food plants for a period of two months. These values may be misleading and untrue for natural conditions since the entire feeding was carried on in cages and upon picked leaves. It would be interesting to see whether similar results are derived from groups of larvæ feeding under natural conditions on the trees. The results of the calorimetry indicate that such might be the case. As the larvæ feeding upon the white oak grew much more slowly, even though there are apparently as much

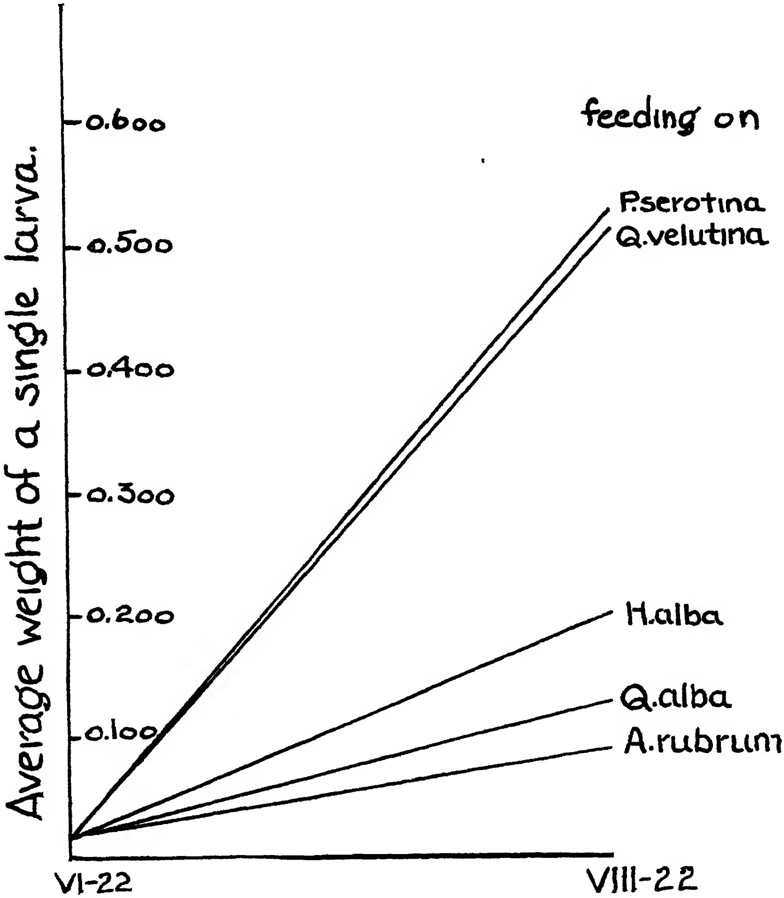

TABLE VI

carbohydrates in white oak as in black oak or wild cherry, it may be inferred that the carbohydrates are not an important influence in the growth of the larvæ. This would bear out the contentions of Peligot and of Hering.

Final Series of Analyses

Between July 23 and 29 this final series of daily analyses was carried on and the averages are tabulated in Table VII. In each case the food leaves were collected from the same tree at 9 A. M., E. D. S. T., and the feces about 9:10 A. M. Ten gram samples of both the fresh and the day-old food and all of the feces collected were immediately put into extractors with sufficient 85% alcohol to make the final concentration about 80% and brought to a boil as quickly as possible. The rest of the procedure is detailed earlier in this paper. In addition ten-gram samples of the leaves were dried for five hours at 110°C to determine the water content.

Table VII

Summary of Final Analytical Data

	Fresh Food			Day old Food			Feces		
	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.
Group I........	2.8	7 9	5.2	6.7	12.7	9.9	1.3	4.3	2.1
Group II.......	1.4	6.3	3.6	0.0	3.9	2.2	1.0	3.3	2.5
Group III......	2.3	5.5	3.5	3.5	7.9	5.5	3.0	5.4	4.0
Group IV.......	3.1	5.2	3.8	2.9	5.8	4.4	3.0	4.9	3.5
Water..........	564.	710.	656.	518.	682.	621.	......	......	103·

All data reduced to represent mgs. per gram of original fresh leaves.

An examination of the table shows only one fact of consequence and that is that the simple and uncombined hexose sugars of Groups One and Two are probably the only ones used by the species under observation. The fact that much of Group Two remains after passage through the intestinal tract rather indicates that only the very simple disaccharides are affected by passage through the digestive tract. Since they are usually autolyzed to reducing glucides upon masceration of the plant tissue, it may be that there is not true larval digestion of them but merely absorption of the autolyzed sugars. This must be proven or rejected in the future.

The difference between the results of analyses of fresh and day-old food due to autolysis and respiration of the leaves (Benay, 1929) sharply brought to mind the fact that concrete information upon the utilization of at least carbohydrates by phytophagous larvæ may be acquired only if those processes are recognized and measured or if a synthetic food be used through which they may be eliminated or controlled.

A Synthetic Food

To this end a synthetic food was prepared and larvæ successfully reared upon it for a short time at the close of the summer. Morgan & Crumb, working with tobacco worms, found that they could induce them to feed on plants totally foreign to their palate by washing the leaves with the steam distillate of tobacco leaves; even thin plates of wax were consumed when so prepared. This principle was successfully used in making an artificial "leaf." A 10% agar suspension in an aqueous distillate of wild cherry leaves was fortified with 5% of gelatine and 5/10% of glucose and cast hot onto warm sterile plates of glass and then cooled under a bell jar. Lengths of cotton thread were cast into this material to act as "stems" so that the "leaves" might be fastened in the feeding cage. Larvæ that had been starved for forty-eight hours were placed in the cage and in an hour were attempting to feed. The "leaves," however, proved too flexible and not a bad medium for molds and bacteria. The addition of benzoic acid to the amount of 1:1,000 corrected the latter fault and a dip in a petroleum ether solution of parowax stiffened the leaves somewhat and prevented surface contamination. Later the benzoic acid was omitted because of the apparently bad effect it had on several larvæ. In the final state the synthetic food was palatable and induced some growth.

A second experiment, that of using starch in lieu of glucose, definitely proved that starch is not utilized by the larvæ. The results of analysis of food and feces are given in Table VIII.

Table VIII
Analyses of Synthetic Foods

	Glucose Food	Starch Food	
	Glucose mg. per g.	Starch mg. per g.	"Glucose" mg. per g.
Before passage	4.2	5.0*	0.0
As feces	1.2	5.1–5.4	0.0

*Theoretically.

The fact that lepidopterous larvæ will feed on completely controlled food should open up a considerable field for investigation. The foregoing experiments were conducted upon insects in the third and fourth instar. I do not know how newly hatched larvæ will take to the diet, as the "leaves" are thicker than normal and rather rubbery. A vitamin source, such as yeast extract, should probably be added for long-time feeding.

Conclusions

1. Hexose sugars probably do not play an important part in the nutrition of *Automeris io* larvæ.
2. Only hexose reducing sugars and disaccharides are utilized by *Automeris io* larvæ.
3. Disaccharides may possibly be made available merely by maceration.
4. Starch is definitely not digested.
5. Calorimetric measurements of the foods used in insect feeding-experiments are important when one is working with natural foods, especially if only partial chemical analyses are made.
6. A synthetic food for phytophagous larvæ has been prepared.

BIBLIOGRAPHY

Acqua, C.
1916. Boll. Labor. Zool. Gen. Agr., Portici, XI, pp. 3-44.
Amick, C. A.
1924. Chemist-Analyst, XVII, No. 4, pp. 10-11.
Armstrong, E. F.
1924. "The Carbohydrates and Glusides." Longmans, Green & Co., 4th ed., London.
Benoy, M. P.
1929. Jour. Agric. Research, XXXIX, No. 1, pp. 75-80.
Hering, M.
1926. "Biologie der Schmetterlinge." Berlin.
Kawase, S.
1918. Jour. Chem. Soc. Japan, XXXIX, pp. 245-294.
Maillot, E. and Lambert, F.
1905. Traité sur le Ver à Soie du Murier et sur le Murier. Paris.
Morgan, A. C. and Crumb, S. E.
1928. Jour. Econ. Ent., XXI, pp. 913-920.
Morrow, C. A.
1927. Biochemical Laboratory Methods for Students of the Biological Sciences. Wiley & Sons, 1927.
Myers, V. C.
1924. Practical Chemical Analysis of Blood, 2nd. Ed., pp. 155-157. C. V. Mosby Co.
Peligot, E.
1867. Ann. Chim. et Phys., (4), XII, pp. 445-463.

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A CONTRIBUTION TO THE STRUCTURAL GEOLOGY OF CENTRAL MASSACHUSETTS *

By EUGENE CALLAGHAN

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INTRODUCTION

During the summer of 1929 the writer was a member of the geological staff of the Metropolitan District Water Supply Commission, engaged in helping to record the geological data of the Wachusett–Coldbrook aqueduct tunnel in Central Massachusetts. In that capacity he had opportunity to examine foot by foot nearly two–thirds of the tunnel section, amounting to about 45,000 feet.* Parallel studies of surface outcrops in areas adjacent to the tunnel were carried on in the hope of throwing additional light on the conditions encountered in the tunnel and in the hope of being able to determine the age relations of the tunnel formations.

Subsequently, because of the problematic character of some of the questions encountered in keeping the records, special permission was requested to carry on certain pure science studies calculated to lead to the solution of some of these problems. This called for much additional field work and laboratory study, which have been carried on as a private endeavor. As a consequence of this later work the writer has had an opportunity to examine in detail all but 4,000 of the 75,000 feet of the tunnel.

The study here presented is concerned chiefly with the structural and petrographic evidence bearing on the origin and subsequent history of these rocks, with definitions of formations, with correlations, and with the relative age of the various formations and structures.

The geological field and tunnel work was under the immediate charge of Mr. Frank E. Fahlquist, Assistant Engineer, and the subsequent studies were under the direction of Dr. Charles P. Berkey, Consulting Geologist on the project. Gratitude is due both Mr. Fahlquist and Dr. Berkey for many helpful suggestions, and to Mr. Frank E. Winsor, Chief Engineer, for opportunity to carry on the studies herein described. Mr. Fahlquist very kindly drafted the section (Plate I). Thanks are also due to the faculty of the Department of Geology of Columbia University for counsel and guidance.

Published work on this area is largely limited to two bulletins, the *Geology of Massachusetts and Rhode Island* (*2*)† by Professor B. K. Emerson, and *The Geology of Worcester, Massachusetts* (*7*) by Mr. Joseph H.

* A description of the tunnel and the method of recording geologic data may be found in the Annual Report of the Metropolitan District Water Supply Commission for Year Ending Nov. 30, 1929. The Commonwealth of Massachusetts, Public Document 147 (in press).

† Throughout the present paper the numbers in italics enclosed by parentheses refer to works similarily designated in the Bibliography.

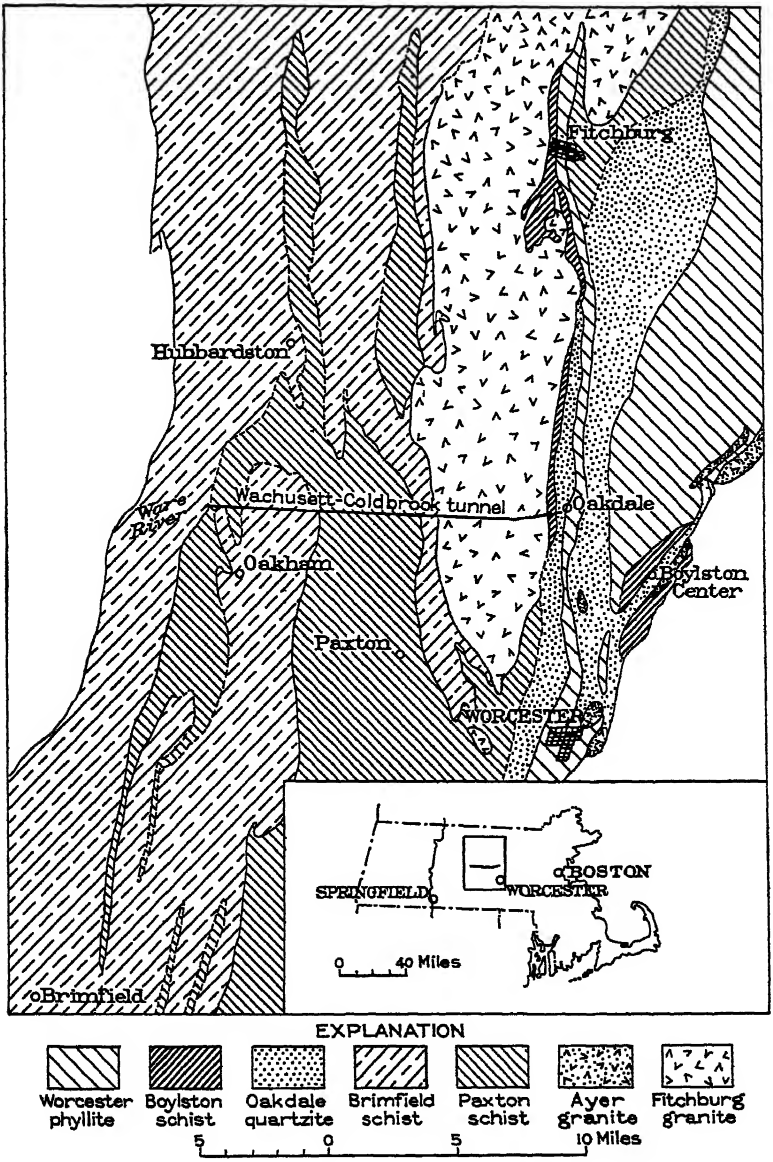

FIG. 1.—Areal geologic map adapted from the Geologic Map of Massachusetts by Emerson, showing the position of the Wachusett–Coldbrook Tunnel. The formational contacts shown are those of the Emerson map, but these contacts along the line of the tunnel are located more accurately on the geologic section (Plate I). The area of Brimfield schist in which Oakham is located is roughly the area of the Ware formation.

Perry and Professor B. K. Emerson. Both papers contain maps, descriptions of formations, and discussion of age relationships. In addition, brief statements of progress in the geological investigation of the tunnel are contained in annual reports of the Metropolitan District Water Supply Commission (*3, 4, 5*). There are also numerous unpublished reports by Dr. Charles P. Berkey made to the Commission on the engineering geology of the project, and these were available to the writer.

ROCK CHARACTER AND ORIGIN

Composition

The object of the following descriptive section is to furnish a picture of the materials which may be grouped into formations in which the various structures occur. Therefore the finer details of the petrographic character are not treated.

There are two principal types of schist penetrated by the tunnel, one of which is a brown feldspathic biotite schist most typically developed between Shafts 4 and 5. It corresponds to the Paxton schist of Emerson (*7*, pp. 130–140; *2*, pp. 60, 62, 86–87, 226, 234). The other is a brown quartz–mica schist most typically developed between Shafts 3 and 4, and 7 and 8, which is the Brimfield schist of Emerson (*7*, pp. 141–150; *2*, pp. 59–60, 68–71, 86–87, 234–235). A short section of phyllitic quartzite which is classed with the Oakdale quartzite of the same author is present at Shaft 1 (*7*, pp. 30–50; *2*, pp. 57–62, 77, 225–227). A dark gray to black phyllite in the geologic section nearly two miles east of Shaft 1 is the Worcester phyllite of Emerson (*7*, pp. 3–28; *2*, pp. 60–64, 77, 225). An andalusite phyllite occurring between the quartzite and granite is the Boylston schist of Emerson (*2*, 67–68).

Igneous rocks are present throughout the tunnel but most abundantly between Shafts 1 and 3. They represent the gray gneissoid Fitchburg granite (*2*, pp. 231-233), gray granitic pegmatites, and a single diabase dike.

FELDSPATHIC BIOTITE SCHIST

On the surface this rock, though schistose, has a massive character and assumes a rusty color on weathering. The color is brownish gray, the brown being caused by the biotite and the gray by an even distribution of feldspar and quartz. The biotite is black when in contact with the igneous constituents. The size of grain rarely exceeds 1 mm. and averages slightly less; it increases, however, in the case of biotite, to more

than 1 mm., and even to 5 mm. when in contact with pegmatite. The feldspathic biotite schist is almost always laminated or banded because of variations in composition and arrangement of pegmatite.

This schist consists chiefly of quartz, feldspar, and biotite with minor amounts of muscovite. The feldspar is of variable grade, ranging from oligoclase to labradorite, but chiefly andesine. Muscovite is commonly directly associated with the biotite. There are also small amounts of apatite, zoisite, garnet, and a carbonate, probably calcite. The whole forms an interlocking crystalline aggregate with orientation less prominent than in the biotite schist.

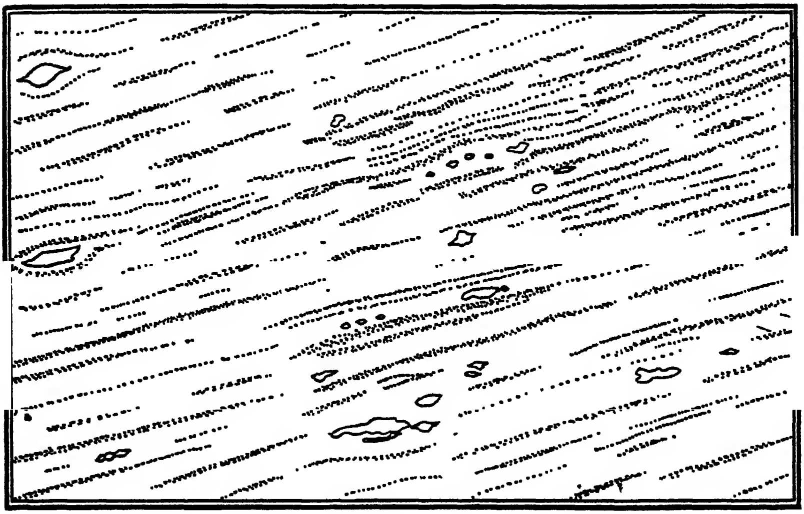

FIG. 2.—Sketch from photograph of tunnel wall at station 304+02 west of Shaft 4, showing the structure of the feldspathic biotite schist. The small inclosed areas represent pegmatite lenses and the stippled streaks represent the green bands composed partly of quartz and hornblende. The area represented is approximately five by eight feet.

There are, in addition, variations which cause the banded character. One of these is produced by a decrease of the quartz and feldspar, and consequent increase of biotite. There is also an increase of quartz over feldspar in some of the bands, which produces a more massive, firmer schist. The most noticeable banding is produced by an aggregate of greenish gray color which is found in bands which average about one-half inch in thickness but may attain widths of three or four inches. The average grain size is less than 0.5 mm. but may increase to 2 or even 5 mm. when in contact with pegmatite. Generally, about

two-thirds of the material in the green bands is composed of light green hornblende and grains of an aggregate made up of clinozoisite intergrown with hornblende. The greater part of the remainder is quartz with a small amount of oligoclase. There are also notable amounts of titanite, and a little apatite, carbonate, chlorite, muscovite, biotite, and garnet. Where in contact with the pegmatite, the hornblende is much larger and the zoisite and hornblende aggregates disappear.

BIOTITE SCHIST

In the weathered outcrop this rock is characterized by a rusty color but in the tunnel it was readily recognized by the flaky appearance it imparted to the tunnel wall. The flakiness is due to the ease of separation along foliation planes.

The color is typically dark to reddish brown, the color of the biotite. The grain size is variable and depends upon the minerals and the prox-

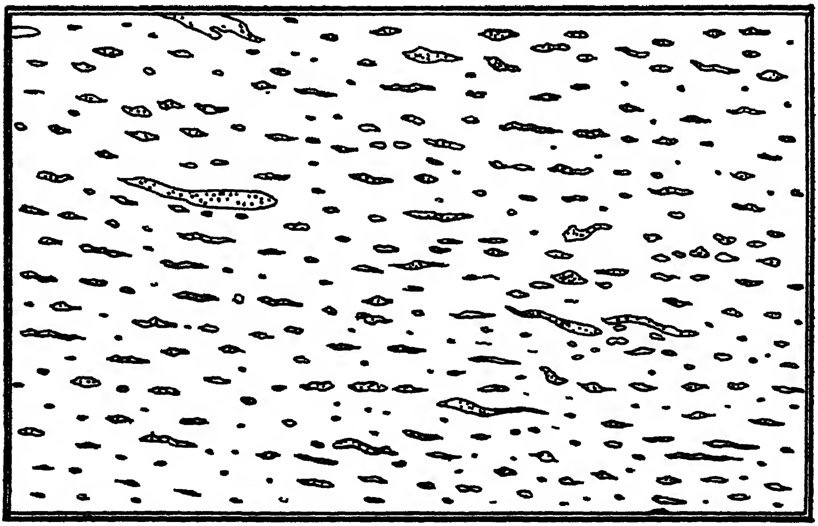

FIG. 3—Sketch from photograph of tunnel wall at station 284+20 east of Shaft 4, showing the biotite schist with characteristic numerous irregularly shaped small lenses of pegmatite. The area represented is approximately five by seven feet.

imity to igneous material, but it is nearly always less than 1 mm. and averages 0.2 mm. to 0.5 mm. The schist is very strongly foliated, microscopically as well as macroscopically, and has a wavy, lenticular appearance caused largely by lenses of quartz and pegmatite, which range in thickness from a few millimeters to several feet.

The pure schist consists primarily of dark to reddish brown biotite, with variable amounts of muscovite ranging from a small fraction to one-third of the total mica content. The quartz occurs, for the most part, in microscopic lenses which, as they increase in size, contain more and more oligoclase–andesine feldspar. There is commonly some quartz associated with the mica outside the lenses. Red garnet, usually less than 1 mm. in diameter, is frequently, but not always, present. Sillimanite or fibrolite

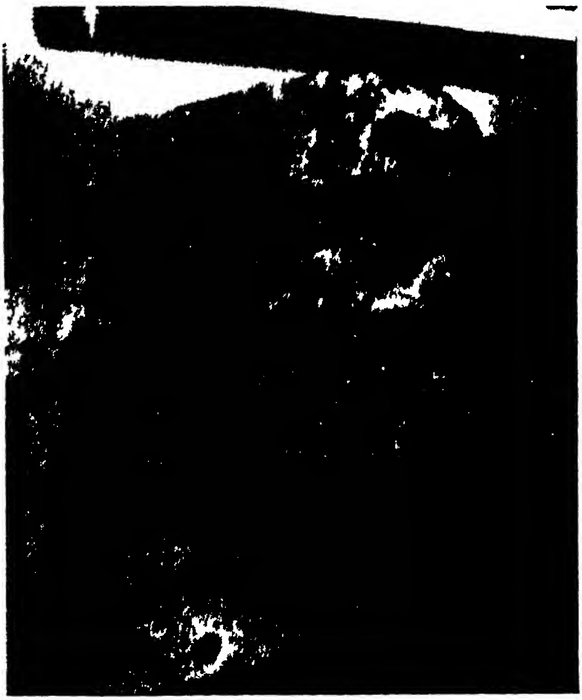

FIG. 4.—A block of meta-limestone. The white bands consist mainly of quartz and calcite and the dark bands are principally made up of diopside and scapolite. A large scapolite crystal is shown at the bottom of the figure

is abundant in some sections but absent in others. Graphite, emphasized by Emerson (*2*, p. 70), was recognized in only a few places.

The biotite schist is generally more variable than the feldspathic type, with the variations ordinarily appearing as definitely recognizable beds parallel to the foliation. By increase in quartz it grades into a biotitic quartzite or in some cases into a quartzite with almost no mica. It approaches the feldspathic schist in composition by addition of andesine

feldspar with consequent decrease in grain size and decrease or disappearance of garnet. In the schist between Shafts 7 and 8, some of the feldspathic layers contain green bands similar to those in feldspathic schist.

A unique variation, a greenish gray meta-limestone, which occurs in beds from a few inches to 15 feet in thickness, is found at stations 682+20, 689+25, 689+86, and 692+50 between shafts 7 and 8. The grains are nearly equant with an average size of 0.2 mm. A very perfect lamination is largely attributable to concentration of different grain sizes and to

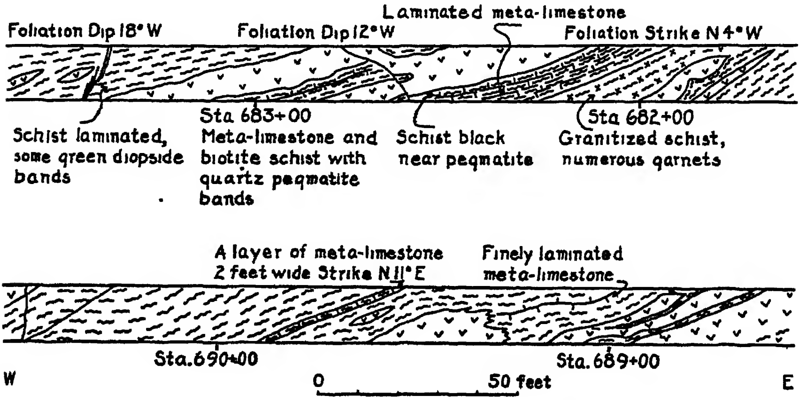

FIG. 5.—Two occurrences of meta-limestone in the tunnel east of Shaft 8, showing the relation to the associated schist and pegmatite.

localization of different minerals. Diopside and scapolite comprise about one-third of the rock, with quartz and some microcline making up the greater part of the remainder. Scapolite crystals were found to be as much as 10 mm. in diameter. Although there is very little hornblende, titanite and calcite are scattered through the rock. There are occasional flakes of graphite and a little pyrite.

PHYLLITIC QUARTZITE

Weathered outcrops have a grayish or brownish color and a characteristic leached appearance, producing a rough surface full of cavities. There is evidence of strong foliation as well as a lamination and even distinct bedding in outcrops in the Worcester Basin. White quartz lenses or veins are nearly always present. In the tunnel it is an extremely fine hard rock minutely fractured so that the structure is very difficult to ascertain though it is apparent on the weathered surface.

It varies from gray to brown, the latter color being caused by very fine biotite. Many specimens from outside the tunnel have a silvery sheen imparted by sericite surfaces. Some of the material is dark gray or black, especially near the black phyllite farther east. This rock is extremely fine, averaging 0.05 mm. in grain size, which is mostly under 0.1 mm. When weathered, the quartzite tends to break readily along foliation planes but the fracture is quite irregular in the fresh rock.

FIG. 6.—Interbedded quartzite (smooth surfaces) and quartzose phyllite in the area of Oakdale quartzite on the north shore of the Wachusett Reservoir. (Photograph by Remington, published by permission of the Metropolitan District Water Supply Commission.)

The composition is variable. One variety predominant in the tunnel section is composed mainly of quartz, some feldspar, biotite and carbonate. The proportion of feldspar to quartz is difficult to determine and probably quite variable. Another type has a slate gray color with nearly equal proportions of quartz and carbonate and a very little muscovite or sericite. In outcrops outside and east of the tunnel a very fine, dense quartzite has been found interbedded with a more sericitic and darker phyllite. The abundance of the carbonate accounts for the leached appearance of most of the outcrops. Veins containing tourmaline cut across the foliation and indicate the subsequent age of igneous invasion.

PHYLLITE

A detailed description of this formation will not be attempted as it is not penetrated by the tunnel and is only brought into the discussion because of its bearing on the question of the age of the tunnel formations.

The color is dark gray to black and the texture is extremely fine; the grain size averages 0.05 mm. The structure is phyllitic with very fine laminae, which are very often found contorted, even on a microscopic scale. The minerals are principally quartz and very fine muscovite or sericite, which make up about equal proportions of the rock. The phyllite commonly has a graphitic appearance but the proportion of carbonaceous matter is usually low and it sometimes does not appear in thin section. In some instances, as at the "Worcester coal mine" south of the section, graphite becomes dominant. On the western side near the phyllitic quartzite the phyllite is interlaminated with thin layers of quartzite; this material, however, becomes less abundant or even wanting farther east.

FIG. 7.—Typical Worcester phyllite on the north shore of the Wachusett Reservoir. The white quartz lenses and bands are mainly parallel to the foliation, which is contorted. The pipe gives the scale. (Photograph by Remington, published by permission of the Metropolitan District Water Supply Commission.)

The phyllite contains quartz veins and lenses, some of which are of microscopic size and which spread apart or cross the lamination. Some of the quartz was found to contain tourmaline.

ANDALUSITE SCHIST

In the surface outcrop this rock has a fine texture and a bright silvery appearance. It becomes brownish on weathering. In the tunnel it has a flaky aspect, which is occasionally relieved by more massive quartzose layers.

The formation as a whole consists of alternate layers of fine quartzose and coarser, more micaceous schist. Finely laminated and brownish in the vicinity of the granite contact, the schist becomes silvery gray toward the east.

Some of the bands are so quartzose as to be classed as a quartzite. For these the average grain size is 0.1 mm. The rock contains, in addition, perfectly oriented muscovite, biotite and chlorite with garnet and pyrite.

The more micaceous bands with few exceptions contain andalusite crystals some of which are as much as 10 mm. wide. They are usually clear, with embayed margins which indicate alteration to fine biotite and muscovite. The foliation is curved and contorted around them. They are larger and more abundant around pegmatite and quartz lenses, suggesting the influence of these substances in the production of the andalusite. The biotite crystals are from 0.5 to 1 mm. in diameter and garnet crystals are as much as 3 or 4 mm. in diameter. These large crystals are embedded in a schistose groundmass, with average grain size of 0.1 mm., made up chiefly of quartz and mica of which one-third is biotite and two-thirds muscovite, with a small amount of albite. The large crystals which do not show any regular orientation appear to have been formed subsequent to the development of the foliation. There is an abundant fine black powder, which may be graphite.

The finely laminated schist near the granite contact is slightly coarser, without andalusite, and very similar to some of the biotite schist included in the granite and in the schist formations farther west.

GRANITE

Outcrops of granite are infrequent along the tunnel line but where exposed, the granite has a gray color, with a slight iron stain which is the result of the decomposition of biotite. Streaks of included schist or of biotite are commonly present.

The color is grayish white, the shade depending upon the abundance of the dark constituents. The granite in the main mass between Shafts 1 and 3 is coarse, averaging 5.0 mm. in grain size for the feldspars, and 2.0 mm. for the quartz and the mica. The micas in the granite in the tunnel west of Shaft 7 are much smaller and the average for the feldspar is 2.0 mm. A gneissoid structure is nearly always present though sometimes only faintly discernible; this is caused chiefly by a parallel arrangement of the micas, but the feldspars are also oriented.

Quartz is always present, but feldspar is in far greater abundance. Orthoclase and microcline occur with lesser amounts of plagioclase varying from albite to andesine. Biotite and muscovite are present in varying quantities. Microcline frequently is found in such a way as to indicate that it has replaced the other feldspars and was evidently formed in the later stages of igneous invasion. The granite of the Fitchburg quarries contains on the average less biotite and more muscovite than the tunnel rock. The biotite in the granite is black as compared to the brown biotite of the schists. Hornblende tends to become prominent, though it is never dominant over biotite. Titanite and apatite, and occasionally rutile, are minor accessories. Pyrite sometimes appears in such a manner as to suggest its primary origin; as, for example, intergrown with titanite. There are micrographic structures, destroyed hornblende crystals, and carbonate, indicating the attack of late end–stage concentration residua.

The proportions of constituents vary from place to place, the principal variants being the micas, especially the biotite, so that a granite may grade into a schist because of the intimate soaking and injection that has taken place. Some of the granite invading the garnetiferous biotite schist contains garnet of the same type, and a part of the main mass of granite contains scattered garnets. Some of the granite has definite bands of biotite, which give it the appearance of an injection gneiss.

PEGMATITE

Pegmatite occurs as sills, lenses, bands, and masses of very irregular shape, which range in size from minute lenses to masses 100 feet in diameter in both the granite and the schist, but it is present only to a very slight extent in the phyllitic quartzite and in the andalusite schist. The average diameter for the larger bodies is nearly 5 feet.

The color is almost always white, from the feldspar, but increase of biotite tends to darken it. In the immediate vicinity of Shaft 2 there

is pink pegmatite, which grades into and belongs to the same epoch as the normal white pegmatite. The grain size is highly variable, with some feldspar crystals as much as 10 or 15 cm. long, though the average length is generally from 2.0 to 10.0 mm. The quartz is commonly much finer than the feldspar, and mica flakes average less than 5 mm. in width. The structure is frequently massive but, where biotite is abundant, it is commonly oriented parallel to the prevailing foliation.

Microcline and quartz are the principal constituents of the pegmatite. Albite, however, and occasionally oligoclase, are present in varying proportions. Microcline is nearly always clear while the plagioclases are generally at least partially altered. These changes probably have been brought about by the attack of end–stage concentration residua. Accessory constituents are muscovite, biotite, black tourmaline and garnet, but not all these minerals are present in each specimen. Generally, but not everywhere, tourmaline is absent where biotite is present and vice versa. Both muscovite with tourmaline, and biotite pegmatites, are present in the granite. Garnet pegmatites occur in the garnetiferous schist and even in the feldspathic schist where it is thin, as in the tunnel west of Shaft 8. Tourmaline pegmatite is found in both biotite and feldspathic schist from Shaft 5 to a point 1000 feet east of Shaft 4. Elsewhere biotite is the principal accessory.

MIXED ROCKS

Since the feldspathic and the biotite schists are practically never free from granitic or pegmatitic injection, in the aggregate they are mixed rocks in which certain characteristic injection structures and rock types are produced.

The igneous constituents tend to be either in the form of separate bodies such as lenses or sheets, or as a very intimate injection and replacement in which there are about equal proportions of materials of either origin, evenly distributed. This produces a rock type very similar to, and not readily distinguishable from, a gneissoid granite. Some of this material may take the form of lenses or sill–like masses.

The pegmatite occurs as large masses of irregularly lenticular shape, as well–formed lenses ranging from several feet to a few millimeters in thickness and occasionally composed of a single feldspar crystal, in some places as sills of various sizes, and in other places as thin bands producing a *lit–par–lit* injection structure. The foliation is almost always bent around the lenses, but the margins are also embayed. Frequently, espe-

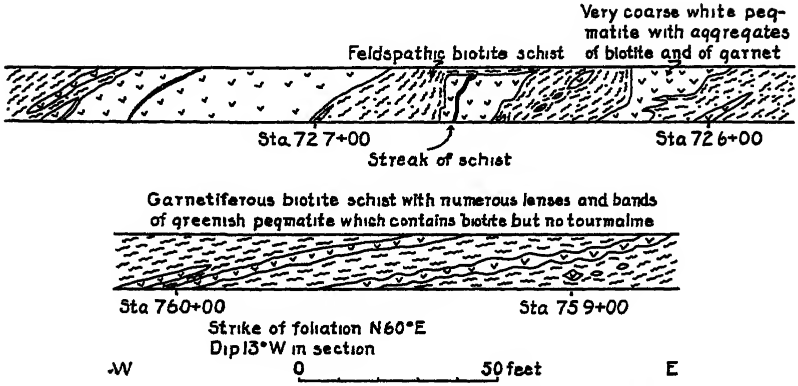

FIG. 8.—The upper sketch shows pegmatite lenses of various sizes and shapes in feldspathic biotite schist. The lower sketch shows narrow sills of pegmatite in garnetiferous biotite schist. Both localities are west of Shaft 5.

cially in the larger masses, the pegmatite contains streaks of schist judged to be residual structures, indicating assimilation and replacement of the schistose material. Measurements were taken on a number of lenses in which there was found a complete spreading-apart of the schist, with almost no replacement.

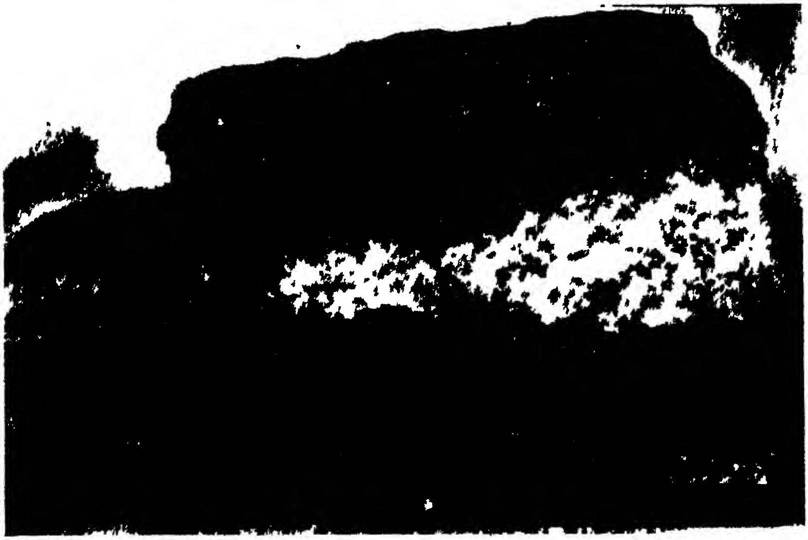

FIG. 9.—Feldspathic biotite schist from the tunnel near Shaft 5. The light streaks are the green bands. The white lens is pegmatite in which the quartz may be distinguished because of its darker color. The curvature of the banding around the lens and the slight embayments along the margin may be noted.

Certain injection and replacement forms are characteristic of the various types of schist, but these vary from place to place. In the feldspathic schist a characteristic injection structure appears in the tunnel wall as a string of pegmatite lenses along a certain schist layer, connected by a band which, if under one-half inch thick, is composed entirely of glassy quartz. If the lenses are less than six or eight inches thick, they are frequently nearly as wide as long. As the size increases, the length increases much faster than the width, producing long thin lenses. If the injection is intense, as in the tunnel in the vicinity of Shaft 8, the peg-

Fig. 10.—Large irregular lens of pegmatite with thin pegmatite lenses and bands in feldspathic biotite schist at station 597+20 east of Shaft 7. The lens has a maximum thickness of three feet. (Photograph by Remington, published by permission of the Metropolitan District Water Supply Commission.)

matite is also in the form of bands which produce a *lit-par-lit* injection structure.

Throughout this schist there are thin lenses less than an inch, and generally less than one-eighth inch, in thickness, but many times as long, composed of glassy quartz which occasionally contains tourmaline. There is also a tendency of single crystals of feldspar to form along the more biotitic layers or laminae, which have proved to be the most susceptible to pegmatitic invasion. There is abundant evidence that the quartz was

more mobile and more penetrating than the feldspar. This is especially well illustrated by lenses which, as they become thinner, become more quartzose and consist entirely of quartz in their thinnest extensions.

The proportion of pegmatite varies. East of Shaft 4 there is between 25 and 50 per cent. of pegmatite and gneissoid granite. In the tunnel between Shafts 4 and 5 the estimated amount of pegmatite varies from 20 per cent. to 2 per cent., but averages 5 per cent. West of Shaft 6 the amount of pegmatite varies from 15 to 75 per cent. In the Shaft 8 tunnel the pegmatite masses over two feet in thickness have an aggregate thickness equal to one–third that of the entire formation, and there is in addition a large amount of smaller lenses and bands.

In the biotite schist, which is easily separable along nearly all foliation planes, the pegmatite lenses are quite uniformly distributed. They are usually long and thin, about six or eight times as long as wide. Lenses over one or two feet in diameter have a more perfect lens shape. The larger lenses in this schist frequently contain streaks or wisps of schist, or scattered flakes of biotite.

Gneissoid granite often appears in the biotite schist, especially in the region of Shaft 3 and in the section between Shafts 7 and 8. This seems to have been formed, at least in part, through the very intense soaking and uniform penetration of especially susceptible schist layers. There are pegmatite veins in this granite, or granitized schist, whose appearance and relation to the remainder of the rock is the same as that of the pegmatites in the schist. Occasionally the contacts are found sharply delineated, while in other instances the schist merges into the granite. The original composition is more easily recognized in places where the igneous material has partially, but nearly uniformly, penetrated the schist. Bands or thin elongate lenses of pegmatite are characteristic of the schist from Shaft 6 westward. Ordinarily the foliation of the inclosing schist is bent around the gneissoid granite lenses, testifying to an actual invasion and increase in volume of the schist in these areas.

The variations of the biotite schist are affected differently. The quartzite contains almost no pegmatite, though it is penetrated by pegmatite quartz veins; the feldspathic schist contains fewer lenses and bands; and the meta–limestone contains some pegmatite and uniformly distributed microcline, which is usually restricted to the igneous rocks.

The phyllitic quartzite contains almost no pegmatite or granite except near the contact with the granite, north of the tunnel, where there are a few lenses of both granite and pegmatite. The rock is, however, full of white massive quartz lenses and veins which tend usually to be parallel to

the foliation and contorted with it, but not crushed or broken. This indicates that they crystallized after the folding took place. They also, in some cases, cut directly across the foliation.

The andalusite schist also contains quartz lenses which are principally restricted to the micaceous bands. These lenses contain on the average less than 10 per cent. of feldspar, and a little biotite. There are also dikes of granite which are in every way similar to the Fitchburg granite and which undoubtedly belong to that formation. There is also a fine-grained garnetiferous granite which is not similar, except in general composition, to anything exposed elsewhere in the tunnel.

Structure

Foliation

The foliation in the feldspathic biotite schist is very even and regular. It is exhibited by (1) the orientation of the biotite, (2) the lamination produced by the more biotitic bands and the green bands, and (3) the orientation of the smaller and thinner bodies of pegmatite, and glassy pegmatite quartz. The quartz and feldspar of the schist are nearly equidimensional and thus do not reveal the foliation. Linear parallelism is only very faintly recognizable in some of the biotitic layers. Irregularities of foliation are produced principally by pegmatite bodies around which the foliation is curved, though it is occasionally directly cut off. Isoclinal folds were found to be extremely rare in the tunnel section; less than a dozen cases were noted.

The foliation in the biotite schist is very strongly exhibited both in the hand specimen and in thin section by the orientation of the quartz and pegmatite lenses. There tends to be much more minor isoclinal folding or contortion of foliation in this schist than in the feldspathic type, though it is not a common feature. In the quartzite the muscovite is oriented and in the meta-limestone there is a strong lamination produced by the concentration of some of the constituents and an arrangement of grain sizes. Linear parallelism can ordinarily be recognized and is occasionally strongly developed in the biotite schist. The average strike of the linear parallelism is N 50° E, and the dip nearly horizontal. In general, the larger the pegmatite or granite mass, the more widely is the attitude of the foliation affected. It is generally true that sharp changes in the direction of the foliation are produced by intrusive masses.

The nearly pure quartzite facies of the phyllitic quartzite are quite massive, but micaceous facies are strongly foliated or phyllitic. The folia-

tion is practically always parallel to bedding and lamination. Very commonly there are folds and flexures, and isoclinal folds several feet wide.

The foliation of the phyllite is strongly developed in all but the quartzite layers. The rock is sometimes slaty, but the foliation is wavy even on a microscopic scale. There are also larger isoclinal folds with amplitudes of as much as three feet. Quartz lenses and veins are commonly irregular and parallel to the contorted foliation though sometimes crossing the foliation in sinuous veins which, though microscopically they show no evidence of folding, in themselves resemble isoclinal folds. They are comparatively straight in the pure quartzite layers.

The foliation of the andalusite schist is parallel to the layers of quartzite and to the contacts with the granite and with the phyllitic quartzite. The folia were often found to be microscopically contorted around the andalusite crystals.

FIG. 11.—Structures in the Fitchburg granite in the vicinity of Shaft 2. The two light bands in the upper part consist of gray gneissoid granite which is pegmatitic at the top. The dark material is a very biotitic granite, which may have been produced by thorough soaking of biotite schist by granitic liquids. The narrow bands and isoclinal folds consist principally of pegmatite. Offsets along joints or small faults are shown in the center. The widest granite band is two feet thick. (Photograph by Remington, published by permission of the Metropolitan District Water Supply Commission.)

The granite always exhibits foliation, though sometimes very faintly. It is shown by (1) the orientation of the mica, (2) by a rude orientation of some of the long feldspar crystals, and (3) by streaks of biotite and included layers of schist. Throughout two-thirds of the tunnel section through the granite the foliation is nearly flat, but even in these places there are minor isoclinal folds, and irregularities in the foliation. In the section between Shafts 1 and 2 the foliation is vertical or dipping at high angles, and contains isoclinal folds. Layers of schist are always parallel to the foliation of the granite and are often found grading into it.

The question then arises whether the foliation or gneissoid structure of the granite represents a flowage structure, or a structure inherited through intimate penetration and soaking of part of the schist material. The general abundance of streaks of biotite, the garnet in some sections, and the stringers of schist grading into granite, all suggest that assimilation has taken place. The very close resemblance of some of the gneissoid granite to schist suggests that the rock formerly was schist, since schist structures are still preserved.

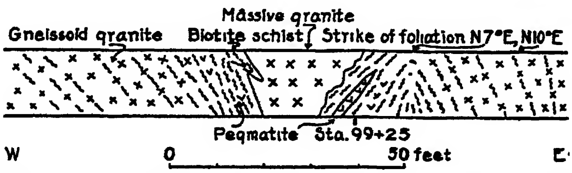

FIG. 12.—Foliation structures in the gneissoid granite at station 99+25 east of Shaft 2, showing the gneissoid structure in the granite and the biotite schist into which it grades, with pegmatite along the foliation planes.

The foliation in many of the granite lenses is continuous with foliation in the surrounding schist, but the folia, curved outward, suggest an expansion of the mass. It therefore appears that in these cases at least the gneissoid structure is inherited from the schist. The fact that in the granite area the gneissoid structure is parallel to the foliation of the schist suggests that the former is inherited, but it is none the less apparent that if schist masses were caught up in a moving magma they would also tend to be aligned with the flow structure. The whole was plastic enough to move, as is indicated by the contortion of the foliation in many places. Thus it is quite possible that both processes are responsible for the foliation structures exhibited, inherited structures being the most significant.

The smaller masses of pegmatite and those without appreciable biotite are massive. Many of the larger masses contain abundant biotite, and

streaks of schist, which are oriented with the prevailing foliation. In some of the pegmatite masses the foliation is curved into, or swirled in, the igneous material.

CONTACTS

The contacts between the various biotite schist and feldspathic biotite schist members furnish some pertinent information concerning the relation of foliation to original structure. First, the contacts are all conformable; that is, the foliation and bedding are parallel on both sides of the contact; second, as the contacts are frequently gradational, it is not often possible to put the finger definitely on the line of contact; and third, the two kinds of schist at several places are interbedded, especially in the tunnel west of Shaft 8 where the contact is a zone 70 feet wide.

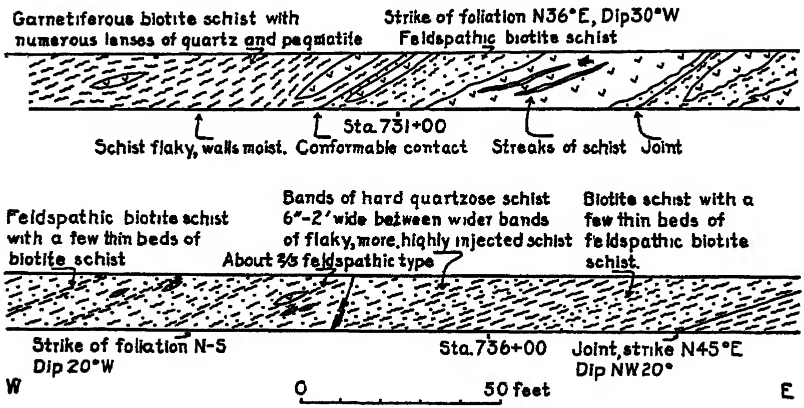

Fig. 13.—The upper sketch shows a sharp contact between feldspathic biotite schist and biotite schist. The lower drawing shows a gradational contact between the same kinds of rock. Both are west of Shaft 8.

It was possible to obtain data on the location of contacts, other than their location in the tunnel, in only two places, Shaft 4 and Shaft 8. At these points a series of specimens from the shaft placed the contact in the shaft at a point within a few feet of where it would have come, drawn according to the dip and strike of the foliation. Another check was obtained on the contacts on either side of the low anticline east of Shaft 6 at stations 476+25 and 522+00. Starting with the eastern contact and plotting the contact above the tunnel parallel to the foliation, it was found that the tunnel again pierced the contact within a few feet of the actual contact. Another, though rather loose, check, is furnished by the anti-

cline between Shafts 7 and 8 whose actual contacts are very nearly in the position that is obtained by plotting the dip of the foliation. Lack of surface outcrops prevents the securing of corroborative evidence. These checks point to the conclusion that the foliation is paralled to the contacts of the formation and is in turn parallel to the original bedding.

Gneissoid structures in the granite near the schist are parallel to the foliation of the schist, indicating either inherited structures or a similarity of forces producing the foliation.

MAJOR STRUCTURES

Folds

Folds shown by the foliation and parallel structures are of two principal magnitudes: (1) small folds a few feet to 700 feet broad in tunnel section, and (2) the major anticlines and synclines of the section. The dominant strike of the foliation is nearly north–south but there are many minor variations. Strikes were found to turn sharply and were occasionally found to be east–west, indicating minor folds which appear to be dome–shaped warps. This is to be distinguished from variations in foliation direction, brought about by the igneous intrusions.

The most significant structure is the anticline between Shaft 6 and the west end of the tunnel. It is over four miles wide in the tunnel section, and is nearly symmetrical, the only variation being about 1000 feet of nearly flat foliation on the immediate east side of the center. The core is composed of gneissoid granite intrusive in the biotite schist. The foliation of the granite conforms to that of the schist. This may represent the roof of the batholith, which is responsible for the abundant granitic and pegmatitic injection in this part of the tunnel and which Emerson (*2*, pp. 233–236) calls the Hubbardston granite. Except for an average finer grain it is not distinguishable from the granite in the vicinity of Shaft 2.

This anticline is separated from a broad, nearly flat–topped anticline 7500 feet wide in the tunnel section, by a fault and almost 2000 feet of nearly horizontal foliation. The east limb of this fold is 3000 feet long and has an average dip of 15° to the east. The west limb is only 700 feet long, with an average dip of 20° to the west. However, the top of the anticline dips 2° to the west. East of this fold the foliation is nearly horizontal for 9000 feet with a very low anticline 6000 feet wide east of Shaft 5. East of station 375+00 the foliation is homoclinal with an average dip of 11° to the east, until the gneissoid granite is reached.

Although it cannot be stated definitely whether the apparent anticlines and synclines in the granite are actual, yet, if the structure is entirely inherited, it would appear that such must be the case. If this is true, the principal structural feature is an isoclinal syncline between Shafts 1 and 2 with its center at station 87+50, where there is a small syncline.

The andalusite schist and phyllitic quartzite both dip to the west at an average angle of 25° with the foliation near the contact parallel to that in the granite.

East of the tunnel in the Worcester Basin is an anticline in which the phyllitic quartzite is exposed with a syncline of phyllite adjoining it on the east. As far as can be ascertained from scattered outcrops of variable dip and strike, the anticline is symmetrical. The dips on the east limb of the syncline, however, tend to be steeper by 15° than those on the west, averaging 40°, while those on the west average 25°. The syncline pitches toward the northeast. In both of these formations the variations of the foliation confuse the delineation of the major structure. Lack of outcrops prevents a definite determination of the relations of formations of the anticline to those exposed in the tunnel.

Faults

Faulting prior to metamorphism and igneous invasion is difficult to recognize, because of obliteration by these processes, and lack of horizon markers in the thick formations. Thus faults can only be recognized or their throw approximated when two formations are brought into juxtaposition. The most notable one of these occurs at station 546+25 west of Shaft 6, where feldspathic biotite schist is separated by a mass of pegmatite from biotite schist. This is interpreted as a fault because of the juxtaposition of the two formations and because of the factors in the correlations of formations on either side. A zone of vertical foliation with a band of mica in the center is interpreted as a fault but the amount of displacement is not determinable. At station 616+25 east of Shaft 7 there is a dike-like mass of pegmatite cutting across the foliation of the schist and dipping to the east, which suggests a fault, but the rock on either side is compositionally the same.

It is to be expected that the igneous substances would enter the fault zones and obliterate evidences of faulting. But the lack of fault contacts of formations, except the one mentioned, shows that for whatever faulting occurred the magnitude of the throw was less than the thickness of the formations.

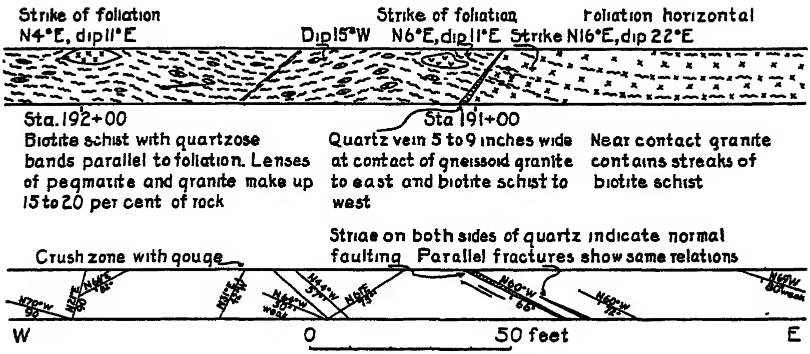

FIG. 14.—Conditions at the contact between the granite and biotite schist between Shafts 2 and 3. The lower drawing is a plan view showing the direction of joints, faults, and veins.

The contact of the gneissoid granite with the schist at station 191+00 is represented as a fault because of the abruptness of the transition and the quartz veins with striations indicating normal fault movement. However, the granite contains streaks of schist of the same type as that west of the contact so that, while the movement was sufficient to bring up the granite, the original transition between the two rock types is still indicated. Furthermore, the lack of extreme crushing and drag indicate a relatively slight movement.

ISOCLINAL FOLDING IN THE SCHISTS

The possibility of isoclinal folding must always be entertained for schists with such strong foliation. However, with the exception of very minor folds with amplitudes of less than a foot, no such folds have been observed in the tunnel in the schists. Their presence in the phyllite and phyllitic quartzite is quite common and their size, generally observed to be less than three feet, may be much greater. It is possible that in the schists the apices of the folds were obliterated in the intensity of the movement, and thus rendered the recognition of larger scale isoclinal folds impossible. However, the very low angle of foliation, the continuity of formations and parallelism of foliation to contacts, and the lack of observed evidence, do not favor large scale folding of this nature.

INDICATIONS OF ORIGINAL STRUCTURE

It has been demonstrated that the layers of the variations from the normal schist types are parallel to the foliation. The quartzite layers

undoubtedly represent original sandstone layers in a more argillaceous sediment. The meta–limestone layers in the Shaft 8 east tunnel are quite uniform beds and are very obviously not of igneous origin. One of them shows a fine lamination, with biotite schist. of its upper side, which suggests original similar organization of these constituents.

The meta–limestone layers and laminae are quite uniform in thickness. The quartzite layers and the feldspathic biotite schist layers are more irregular in thickness and continuity. A mass of feldspathic biotite schist at station 698+50 in the biotite schist has a decided lens shape. Such variation would be expected of the coarser constituents in the original.

The contacts furnish the best evidence for the parallelism of bedding and foliation. This is shown in the contacts which are abrupt, as well as those in which there is a wide zone of interbedding of the two types of schist. This is illustrated especially well by the contacts between the feldspathic schist and the biotite schist west of Shaft 8. Biotite schist beds in the feldspathic schist in the Shaft 8 west tunnel are quite uniform and very closely resemble interbedded sandstones and shales.

The parallelism of foliation with contacts of different rock types is another indication that, in general, the metamorphic structures conform rather closely to the original sedimentary structures. This is also indicated by the broad general relations of the rock types and their structural assemblage, and their occurrence in very continuous layers.

Conclusions as to Original Character of the Chief Rock Types

FELDSPATHIC BIOTITE SCHIST

The composition and structure of the various types of metamorphic rock yield certain evidence concerning their character before they were metamorphosed. The feldspathic biotite schist is believed to have been originally a sedimentary rock. Sedimentary origin is indicated by (1) the abundance of quartz and biotite, (2) the green quartzose zoisite–hornblende bands, (3) the very biotitic streaks and bands, (4) the wide lateral distribution, and (5) the gradational character of some of the contacts with biotite schist represented by alternating layers of the two types. An igneous origin is suggested by the abundance of feldspar. However, the feldspar is a moderately basic plagioclase, and a more acid type would be expected to occur with the 30 per cent. of quartz. The finely laminated variations and the bedding are of such a character that they could not reasonably be expected in material formed by igneous processes.

The exact original character cannot be described with certainty because of recrystallization and the introduction of igneous constituents. However, the abundance of microcline in materials definitely related to the igneous invasion, and its absence from the pure schist, indicate that the plagioclase feldspar has been recrystallized from the original constituents. The combination of plagioclase feldspar and quartz suggests very strongly that the type of rock under discussion was originally a feldspathic sandstone. Argillaceous impurities are indicated by the mica, and calcareous impurities by the green bands containing hornblende, garnet, and zoisite. Original iron oxide is probably represented by the iron in the biotite. Quartzose beds are represented by the nearly pure quartzite, and shale beds by the layers of biotite schist.

It would seem from the evidence presented that the original rock was an impure sandstone, possibly containing as much as 40 per cent. of feldspar, with quartz, clay, calcium carbonate, and iron oxide.

BIOTITE SCHIST

Sedimentary origin of the biotite schist is indicated by (1) lack of appreciable feldspar, except that related to pegmatite and granite, (2) the dominance of biotite with some muscovite, (3) the presence of fibrolite, (4) interstratification with feldspathic biotite schist, especially as contacts, (5) the presence of beds of quartzite and meta-limestone, and (6) the extensive areal distribution. The dominance of mica, the presence of fibrolite, the relatively low content of quartz other than that brought in by the igneous invasion, and the absence of feldspar, point to the conclusion that the biotite schist was originally a shale. The beds of feldspathic schist probably represent original layers of impure feldspathic sandstone. The beds of quartzite were undoubtedly quartz sand layers, and the meta-limestones were originally limestone layers in the shale. The garnet in much of the biotite schist suggests that the original contained calcareous material. Original iron oxide is probably represented by the iron in the biotite. Original carbonaceous matter is now graphite.

PHYLLITIC QUARTZITE

This was obviously originally a sedimentary rock because of its siliceous nature, the quartzite beds, and the interbedding and interlamination with phyllite. Some of the beds are nearly pure quartzite, showing that the original rock was a quartz sandstone. Other layers contain fine sericite and biotite and calcite, indicating argillaceous and calcareous mate-

rials in the original sandstone. Still other layers show gradation toward the micaceous phyllite, suggesting a gradation from sandstone to shale. The extremely fine grain suggests an original sediment of the nature of silt, but possibly the fine texture has been produced by recrystallization. Beds of quartzite several feet thick, and thin laminae less than an inch thick, indicate the variability in composition of the original sediment.

PHYLLITE

The high proportion of sericite to quartz in this rock suggests very strongly that it was originally a shale. The graphite indicates carbonaceous impurities which in the beds at the "Worcester coal mine" very nearly equalled in amount the other components. The interbedded layers of phyllitic quartzite indicate original layers of sandy shale or shaly sandstone.

ANDALUSITE SCHIST

The dominance of quartz and mica and the presence of alternating highly quartzose and micaceous layers suggest that this rock was originally an argillaceous sediment with interbedded quartz sand layers and laminae. The andalusite further suggests the aluminous character of the original sediment. Garnet indicates the former presence of some calcareous material. If the black powder is graphite, the original sediment was carbonaceous.

The Metamorphic Process

It might be expected that this investigation would yield some evidence concerning the causes of the metamorphic structures and minerals observed. Such evidence is best studied in an area which shows progressive stages of metamorphism—which this area does not. However, certain points may be emphasized in this connection. First, there is the very gentle dip, or even horizontality, of the foliation, without any recognized major isoclinal folding or overthrusting. This indicates that horizontal compressive stresses have not been a potent factor in metamorphism. Second, there is no evidence in the normal schists of cataclastation, or of development of the schistose structure by crushing and streaking out of the minerals. There is only recrystallization with a tendency of the unequidimensional minerals to be sufficiently oriented to give a schistose structure to the rock. Third, the parallelism of foliation with bedding and contacts seems to indicate that these original structures are actually the determining factors in the orientation of the planes of foliation. There has been, however, a horizontal stress, possibly caused by regional

movements during the closing stages of the igneous invasion, which has produced the linear parallelism or streaking out of minerals. This seems to suggest a distention or stretching of the mass.

If metamorphism has not been caused by horizontal compression, thrusting, and kneading of the rock, vertical pressure must be considered. If these rocks are really of Carboniferous age and the Triassic sediments were derived from them, it would appear that their cover was not very great and that load pressure alone would not have been sufficiently great to produce metamorphism.

The remaining, and apparently the principal, factor seems to have been the pegmatitic igneous invasion which thoroughly penetrated every part of the mass, crystallizing along bedding planes and other planes of weakness—principally the former—either in the form of quartz–feldspar pegmatite or as thin lenses of quartz. It thus brought about the recrystallization of the original constituents and the orientation of the elongate or flat minerals parallel to the original stratification because this was the direction of least resistance. This would tend even more to be the result if vertical rather than horizontal pressure were the more effective, and a horizontal distention would heighten the effect. Furthermore, the minerals in sediments tend to be oriented with their long axes parallel to the bedding. It would be expected that, in recrystallizing, the minerals would have a tendency to grow in the same directions, producing foliation parallel to the bedding. The invasion of the molten igneous materials must have made the original rock quite plastic, a condition which contributed to the ease of directional recrystallization and the ability of the crystallizing pegmatite masses to push aside the foliation laminae.

It might seem that a thick cover would be necessary if such processes were to go on. However, the abundant quartz veining in the Carboniferous Worcester phyllite, bearing much the same relation to the bedding of the phyllite as the pegmatite to the schists, contains tourmaline and occasionally feldspar. This indicates its close relation to pegmatite. Consequently, the cover was sufficiently thick for similar processes to take place in rocks of definitely Carboniferous age, and only a slightly thicker cover would have been necessary for the greater metamorphism and injection of the schists farther west.

SUBSEQUENT HISTORY

Subsequent petrographic changes are largely limited to chloritization of biotite; to partial–to–complete sericitization of the feldspar, giving it a green color in some places; to the introduction or production of car-

bonate in the minerals and along minute fractures; and to the introduction of pyrite along foliation planes and along minute fractures. This condition is widespread in certain parts of the biotite schist, especially in the vicinty of Shaft 3 and Shafts 7 and 8. The inclosed granite and pegmatite are affected as well. The schist becomes greenish gray and is more flaky. This type of alteration is largely restricted to areas of secondary shearing, but because of the minerals formed it appears to be related to solutions coming from a cooling igneous mass, possibly evidence of the last chemical activity of the invading granitic magma.

Joints, Faults, and Veins

The dominant trend and direction of dip of some 2000 of the joints, faults, and veins, throughout the tunnel section, are illustrated by the circular diagrams (Plate I), each diagram representing the average condition in those portions of the section in which conditions are nearly uniform. The length of line represents the relative strength and number of joints in the various joint systems, and the direction represents the compass direction of the average of the joints in that section. The direction of dip is the dominant one for each joint system. The term fault is used in this discussion to distinguish those fractures in which displacement could be recognized even though measured only in inches.

Summary of Observations

The multitude of minor variations and individual peculiarities of the jointing are too numerous to describe, but a number of summarized observations may be made:

(1) There are two principal systems of jointing, one striking northeast, the other northwest. A system striking north–south appears in parts of the western portion of the section, generally at the expense of the northwest system.

(2) The northeast system is usually the strongest—that is, the more persistent—with smooth walls, more frequent indications of relative movement, and greater number. The northwest system is generally weaker and the trends of the joints more diverse.

(3) The northwest system dips dominantly to the southwest, almost throughout the section. Joints which strike nearly north–south are either vertical or dip dominantly to the west.

(4) The northeast system in the eastern half of the section dips prin-

FIG. 15.—A group of strong joints with horizontal striations in gneissoid granite at station 147+50 west of Shaft 2. The strike is N 81° E and the dip is 64° south. (Photograph by Remington, published by permission of the Metropolitan District Water Supply Commission.)

cipally to the southeast, but in the western half dips chiefly to the northwest.

(5) Joints striking between N 50° and 90° E tend to have a steeper dip (60°–90°) than those with other trends. These joints have more indication of horizontal movement than any other system.

(6) Most of the normal faults come within the range of N 40° W to N 45° E and dip chiefly to the west.

(7) Joint systems change at three out of fourteen contacts so that change of rock cannot be regarded as a factor in jointing. There is no marked change in crossing the fault contact between the gneissoid granite and the biotite schist, but there is a change in crossing the fault at station 647+00 west of Shaft 6.

(8) Joints are not numerous in the region of nearly horizontal foliation in the vicinity of Shaft 5, but are even fewer in the more steeply

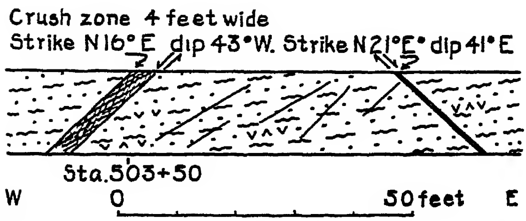

FIG. 16.—Normal faults with crush zones dipping in opposite directions in feldspathic biotite schist at station 503+50 east of Shaft 6.

dipping foliation west of Shaft 5. Consequently, the abundance of joints does not depend on the angle of dip of the foliation.

(9) By far the greater number of joints in the phyllitic quartzite and andalusite schist east of the granite, trend east–west, and are vertical or dip steeply to the south. They are approximately normal to the strike of the foliation and the linear parallelism. They terminate abruptly at the granite contact.

(10) All those fractures showing movement with a vertical component in which the direction of movement could be recognized were found to be normal faults even though they dipped in opposite directions. No evidence of reverse faulting was found in the section.

(11) The joint systems are quite variable in that part of the granite in which the foliation is steep; but they are comparatively uniform west of station 119+00 where there is a marked change from northeast to northwest jointing, coinciding with a change in direction of dip of the foliation.

(12) The relative movements of the walls of the fractures showing a horizontal component are very nearly equally divided between the two possibilities.

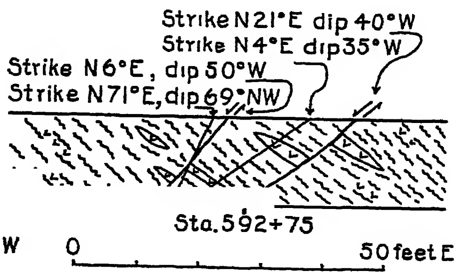

FIG. 17.—Faults in biotite schist at station 592+75 east of Shaft 7, showing offsetting of pegmatite amounting to four feet for the fault on the right.

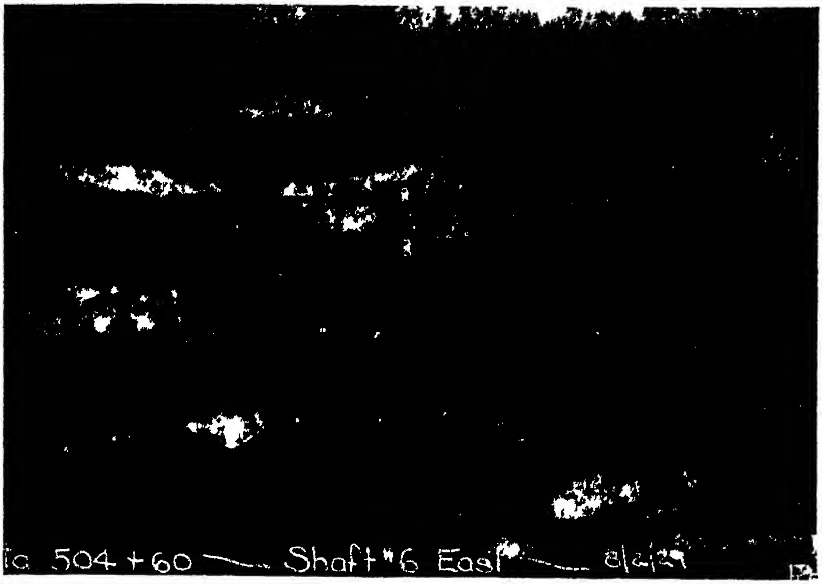

Fig. 18.—Normal fault of low angle of dip and slight displacement in feldspathic biotite schist at station 504+60 east of Shaft 6. A characteristic string of small pegmatite lenses connected by a thin line of quartz is shown in the lower left. (Photograph by Remington, published by permission of the Metropolitan District Water Supply Commission.)

(13) The northwest joints, while weak and not notably persistent, are extremely abundant immediately west of Shaft 4. They all show normal fault movement with a displacement, on most, of but a fraction of an inch.

(14) In the greater number of instances the actual amount of displacement along the faults could not be determined, but where it could be measured it was found to range from a few inches to three or four feet. Even strong crush zones were found to have displacements of less than three feet, indicating that great displacement is not necessary to bring about this condition.

(15) A number of low angle crush zones striking north–south and generally dipping west occur in the vicinity of Shaft 7. Some of them consist of a branching group (Fig. 19) in which displacement has not been more than a foot; yet the crush zones are six inches wide. While such low angle fractures might be expected to be reverse faults, normal faulting was indicated for all those in which the direction of movement could be detected.

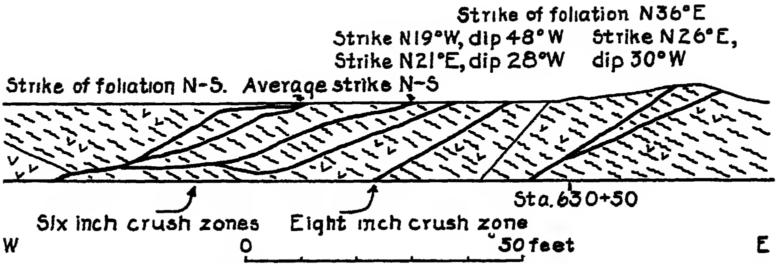

FIG. 19.—Branching normal faults with crush zones in biotite schist at station 630+50 west of Shaft 7.

(16) Alteration of the wall rock, in the form of chloritization of biotite, occurs along the joints and faults in zones varying from a fraction of an inch to several inches wide. A greenish clay gouge in the granite and a dark, or even black, gouge, in the schist, are formed along some of the joints and crush zones. Veins of various substances fill most of the fractures. Most of the joints are lined with chlorite and almost all contain calcite. Wide calcite veins occur chiefly in the northwest system.

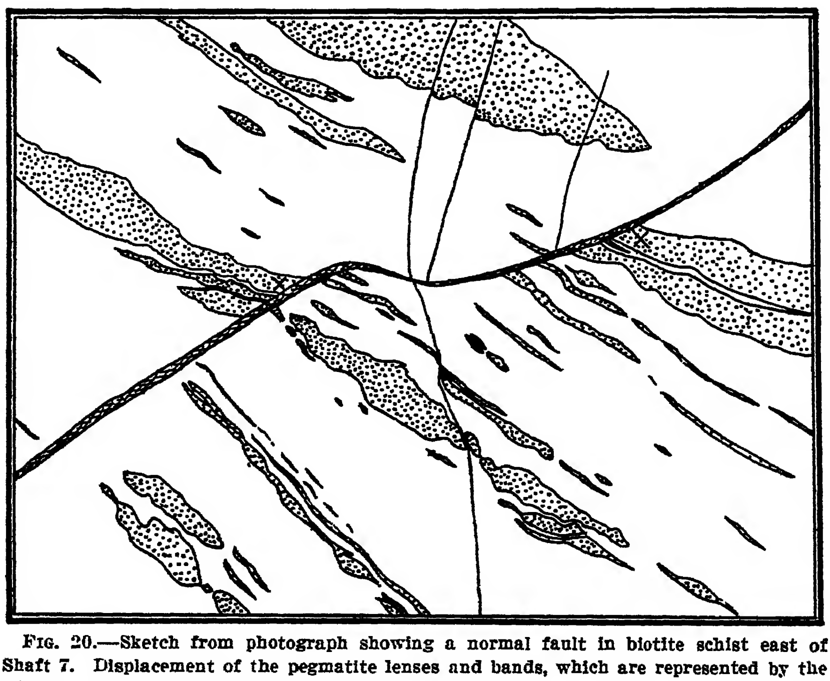

FIG. 20.—Sketch from photograph showing a normal fault in biotite schist east of Shaft 7. Displacement of the pegmatite lenses and bands, which are represented by the stippled areas amounts to about three feet.

Multitudes of joint fissures are filled with pyrite, which is also found in thin sheets between the folia of the flaky biotite schist, especially in those parts which are chloritized, and in the andalusite schist. This pyrite is probably not original pyrite formed in the sediments, as is contended by Emerson (*2*, p. 70), but came in later along planes of weakness. Some of the joints in the feldspathic biotite schist were found to contain stilbite and chabazite.

Quartz veins are comparatively rare, occurring chiefly along joints, and are usually crushed, indicating subsequent movement. Most of them trend between N 5° E and N 40° W, though they are not restricted to this range of direction. Five such veins occur in the north–south system in the western part of the tunnel. Pyrite is almost always present in the veins, and one small mass of quartz with galena, pyrite, and sphalerite was found in the granite west of Shaft 2.

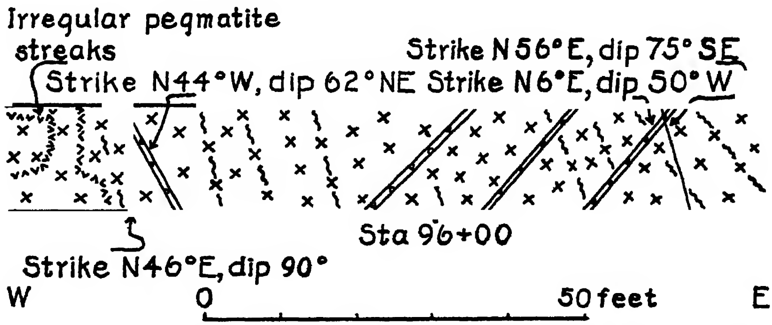

Fig. 21.—Sharply defined pegmatite dikes less than one foot thick in gneissoid granite at station 96+00 east of Shaft 2. The more common, irregular streaks of pegmatite are shown at the left.

(18) The schist east of Shaft 4 and in the vicinity of Shafts 7 and 8 exhibits a shear structure, always parallel with the foliation as far as could be determined, and affecting the inclosed pegmatite as well. The schist is extremely flaky, contains much pyrite along foliation planes, and the mica is chloritized. The shear structure is apparently due to post-metamorphic forces renewed in the direction of least resistance, the original foliation structure. It may have been produced by local upthrusts.

(19) Sharply defined pegmatite dikes cutting across the foliation are extremely rare in the tunnel section and are almost entirely limited to the eastern part of the granite. They have a wide range of strike, but nearly half of them trend between N 15° and 45° E, and dip mainly

northwest. There are joints along the margins or centers of many of these pegmatite dikes.

A diabase dike 310 feet wide, with an approximate strike of N 35° E, is penetrated by the tunnel east of Shaft 4. It is fine grained near the margins, but coarser toward the center, and without any obvious contact effects on the gneissoid granite with which it is in irregular contact. Jointing is blocky and irregular, and the major joint systems could not be identified within the dike.

(20) It was not found possible to establish any definite time relations between the intersecting systems of joints. Intersecting joints, either one or both showing signs of movement, were found not to offset each other.

(21) The linear parallelism or streaking out of minerals, observed at a number of points in the biotite schist, averages N 50° E in strike. This structure strikes nearly north–south in the andalusite schist and phyllitic quartzite east of the granite.

Interpretation

The interpretation of these observations made in rocks of such complex character and history is fraught with difficulty and uncertainty. First, the observations have a linear rather than an areal distribution. The drift cover is so widespread that there is no chance to make adequate surface observations. Second, though dominant characteristics may be recognized, there are so many exceptions to every rule that it is questionable if any generalized interpretations are valid. Third, there is little agreement in the literature as to the interpretation of these structures. Fourth, the possible contributing causes of jointing, such as cooling and contraction of the magma, regional tension, regional compression, torsion, unloading, release of stresses set up during metamorphism, and recurrent regional stresses acting from various directions, are so varied that it is hardly possible that any simple explanation holds for all the structures observed. Consequently, the interpretations made here are only suggested as having an element of plausibility in explaining some of the observations.

Fig. 22 represents in a generalized way some of the observed dominant characteristics of jointing, especially as shown in the vicinity of Shaft 4. It shows the strong northeast system dipping steeply to the southeast, with indications of relative horizontal movement, the weaker northwest system which contains most of the normal faults and veins dipping

more gently to the southwest, and the linear parallelism or grain of the rock approximately normal to the northwest system.

The top block (No. 1) shows the directions of fracturing and the direction of linear parallelism. Block No. 2 has slipped downward as a normal fault along the northwest surface and in doing so has sheared off on the northeast surface and dragged along on that surface, producing a

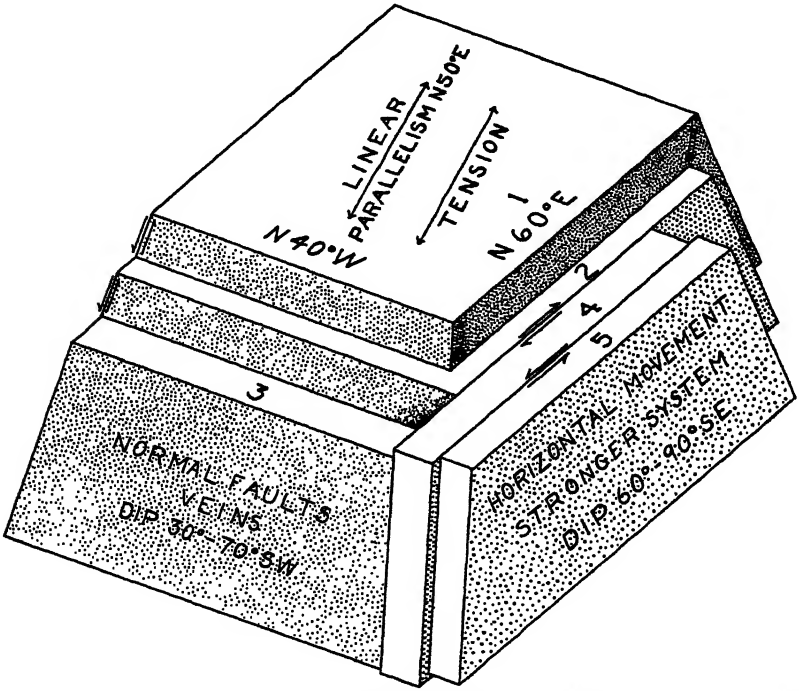

FIG. 22.—Diagram illustrating the dominant characteristics of joints, faults, and veins in the vicinity of Shaft 4.

horizontal component of movement, the resultant of which would be indicated by striations tilted to the southwest, an observed condition at a number of places. Block No. 3 represents the normal fault slicing, which continues interminably. Block No. 4 has moved in the same direction as No. 2 but only with the horizontal component. Block No. 5 represents an observed condition of opposite relative movement, possibly indicating lag.

Normal faulting is generally regarded as implying a distention of the mass in a direction normal to the direction of faulting. Such a disten-

tion of mass would be expected to produce openings along fractures, hence accounting for the greater number of veins in this direction. The only line of corroborative evidence is the linear parallelism or grain of the rock, the axis of which is parallel to the axis of elongation or distention of the rock and formed when recrystallization took place under directed stress. The linear parallelism was found to be approximately normal to the northwest system of fractures, which may represent fracturing of the rock by a continuation of the same force when deformation by flowage was no longer possible. The reason for the tension in this direction must be sought in regional studies conducted over a large area. It may be recalled that rarely was one joint found to displace another. Furthermore, fractures only a few feet long were found to show a displacement of a fraction of an inch in the center, showing that the rock mass did not behave as a brittle solid in which fractures are continuous, but rather as a somewhat inelastic mass in which movement is distributed in a great many discontinuous fractures, each with a very slight relative movement.

Intersecting systems of joints are also explained on the basis of compressive force applied along a line approximately bisecting one of the angles, but it has not been demonstrated whether the force comes from the direction of the acute or obtuse angle. Since the folding may be due to an east–west compressive force, it might appear that the same compressive force produced the joints, but the accumulated evidence points to the fact that the folding is older than the jointing which is not specifically related to it.

There are undoubtedly many other factors concerned in producing the conditions set forth above, but it is not possible in the present state of knowledge to identify these influences with any particular system.

GROUPING OF ROCK VARIETIES INTO FORMATIONS

Bases of Formational Grouping

In delimiting formations of metamorphic rock it is necessary to take into consideration their value as a unit capable of being mapped. This depends upon (1) compositional continuity and variation, (2) thickness, and (3) persistence. In the tunnel the relations between different rock types appear comparatively simple and it would be possible to consider each bed of a certain rock type a formation, as the greatest thickness of each is not less than 400 feet; and they may be correlated throughout the 14 miles of tunnel. Too, the same rock type, with its variations, is persistent throughout. However, it is necessary to consider also the possi-

bility of mapping these formations on the surface. Outcrops are very scarce, at least in the vicinity of the tunnel, because of the heavy drift cover. It is interesting to note in this connection that Perry and Emerson (*7*, pp. 143–147) cite only one instance of finding the relation between the Paxton (feldspathic) schist and the Brimfield (biotite) schist. In western Worcester they found the Brimfield overlying the Paxton and therefore concluded that there were only two formations with this relation.

The composition serves to distinguish two rocks and that is the basis of Emerson's formational divisions. The tunnel section reveals that there are two thick layers of feldspathic biotite or Paxton schist, separated by a thin layer of what is principally biotite or Brimfield schist. This combination, in turn, lies between two thick layers of biotite or Brimfield schist.

Nomenclature and Definition of Formations

In general, it would appear that the thin biotite schist layer would be difficult to recognize and separate, particularly as it is largely feldspathic toward the east, and so for general mapping purposes would be included more satisfactorily in the Paxton schist formation. It appears from the geologic map of Massachusetts (*2*, map) that Emerson recognized this thin layer in a few places but has not shown how he interpreted it. The fact that the Brimfield schist is separated into two parts is shown not only in the section along the tunnel but also on the geologic map when interpreted in the light of the structure exhibited in the tunnel section.

It becomes necessary, then, to obtain separate designations for these two formations. Their only lithologic difference is that the topmost biotite schist exhibits less variation in the form of meta-limestone, and feldspathic biotite schist, than the lower member. The name "Brimfield" is taken from the town of that name which is twenty miles south-southwest of the west end of the tunnel. The schist in this locality, as it appears from the location of the formations on the areal geologic map, belongs to the upper formation so that if the name Brimfield is to remain it should be applied to this formation. If this is the case, then only the lower formation need be designated by a new name, and since the formation occurs along the Ware River near the village of Coldbrook, the name Ware is proposed.

In summation, the name Brimfield is retained for the uppermost biotite schist formation between Shaft 4 and the granite and in the western end of the tunnel. The name Paxton is retained for the two thick members of feldspathic biotite schist and the thin middle member which in its easternmost exposure in the tunnel is largely feldspathic but which

is mainly biotite schist to the west. A new name, Ware, is proposed for the biotite schist which is found underlying the feldspathic Paxton schist in the anticline in the western part of the tunnel.

This grouping gives a true formational significance to the names rather than having them represent rock types. It also has the advantage of utilizing existing nomenclature, with the introduction of the least number of new terms. This study does not show need of revision of the existing nomenclature of the formations of the Worcester Basin, the phyllitic Oakdale quartzite, the Worcester phyllite, or the Boylston schist.

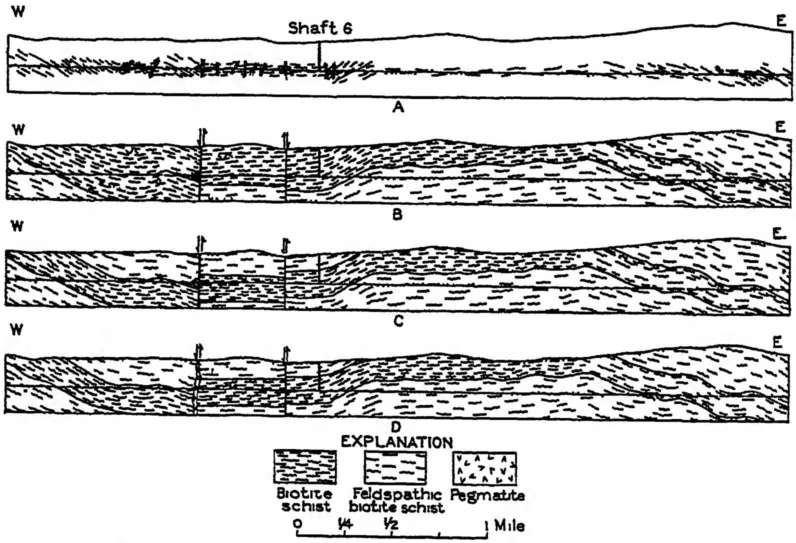

FIG. 23.—Diagram illustrating various interpretations of conditions in the vicinity of Shaft 6.

CORRELATION IN THE TUNNEL SECTION

A glance at the section will show that the relations of the formations on the homoclinal structure between the east tunnel of Shaft 6 and the granite of Shaft 2 are established by a series of contacts without any recognizable breaks. This includes the Brimfield as designated in this paper, the upper feldspathic member of the Paxton, the biotite schist member, and the upper part of the lower member of the Paxton. A low syncline to the west in the vicinity of Shaft 6 contains a break requiring interpretation.

Observations concerning this section are represented in Fig. 23*a*. The contact between the feldspathic schist of the lowermost member of the

Paxton and the biotite schist member at station 522—00 is conformable and transitional. The dip of the foliation varies from 13° to 25° to the west and the strike is N 16° E. The biotite schist, with some characteristic quartzose interbeds, continues 2425 feet to station 546+25 where it ends abruptly against a mass of pegmatite 60 feet wide.

The foliation is nearly flat, with some minor irregularities, to station 545+00. Secondary deformation structures in the form of joints and shear planes begin a short distance west of the contact and from station 525+25 to the region of the shaft both the schist and the pegmatite are thoroughly sheared, with the main shear structure dipping to the west approximately parallel to the foliation. It is traversed by gouge-filled fractures, which intersect and dip both to the east and to the west, but without indications of direction of movement. There are a number of minor crush-zones throughout this section, one of which revealed relative vertical movement with the west side thrown down. There is a narrow pegmatite dike at station 535+50, parallel to a joint which indicates some movement near the close of the igneous epoch, but there is no evidence of major displacement.

At station 532+65 there is a zone of vertical foliation or streaks of biotite in a pegmatite mass with schist on the west side in a syncline 100 feet wide. There is a vertical band of coarse chlorite 15 inches wide and with a slight amount of gouge associated in the center of this zone. The vertical streaking and lack of crushing show that this was a plane of movement possibly before and during the igneous invasion, but the relative movement is not definitely indicated. A slight bending of the foliation suggests that the east side went down, whereas the eastward limb of the syncline, if it represents drag, suggests that the west side is down. In any case, the displacement is not sufficient to bring in a different schist.

The contact between the biotite schist and the pegmatite at station 546+25 is nearly vertical and quite abrupt. The foliation strikes N 5° W and dips 15° E. There is a zone of crushing in and near the contact which dips 80° E, but the direction of relative movement is uncertain. There are no prominent joints to the west. The feldspathic schist west of the pegmatite dips 30° E and strikes N 60° E. The contact of the feldspathic schist above, with the biotite schist below, at station 550+00, is conformable, with an anticline and a syncline to the west. Feldspathic schist is exposed for 325 feet along the tunnel, representing over 100 feet of thickness.

The evidence of specimens taken from the shaft is indecisive as three specimens from the upper part of the shaft are more representative of the

biotite than of the feldspathic schist, though so badly injected that they might represent either kind of schist, or biotite schist interbedded in the feldspathic type.

There are several possible interpretations to be made in constructing and correlating the section. In Fig. 23*b* it is assumed that the 100 feet or more of feldspathic schist represents only a feldspathic layer in the biotite schist, which extends all the way to the surface, and that the east wall of the fault at station 532+65 has moved downward. The secondary faults and crush zones are not taken into consideration, for they do not bring in a new formation, their total displacement where revealed is small or else is unknown, and they dip both to the east and west.

In Fig. 23*c* it is assumed that the feldspathic schist at station 547+00 at the westernmost fault represents the base of the upper member of the Paxton. The biotite schist below it is of a thickness nearly equal to that at, and east of, Shaft 6. The movement of the primary faults represents a cumulative drop to the west. This does not conform to the dip of the crush zone at the fault or the dip of the foliation. The crush zone represents the secondary deformation, while the primary deformation is represented by a fault now obscured by the pegmatite. The foliation may not have been affected in this competent schist. A marked difference in joint systems on either side of the fault at station 546+25 may indicate a lack of continuity of structure and therefore a fault.

In Fig. 23*d* it is assumed that the pegmatite has penetrated and obscured the original fault. The fact that the two layers of biotite schist on either side of the fault are of nearly equal thickness where they can be measured, and their similarity of composition, except for the feldspathic character of the center of this member to the east, suggest very strongly that they are the same bed and that nearly the same thickness continues throughout the section. This seems to be the most reasonable interpretation. In Fig. 23*b* a difficulty would be realized in requiring the biotite schist suddenly to thicken from 400 feet to nearly 1000 feet and then thin down to 175 feet west of Shaft 8. If it is a new formation it is not possible to match it with anything in the section or in the geologic map. Therefore, Fig. 23*c* appears to represent the simplest of the possible interpretations and to conform as well as any other to the observed facts.

East of the fault there is the large anticline which is represented not only by the cross section but suggested by the areal distribution of formations on the geologic map (Fig. 1). On the east limb the feldspathic

lower member of the Paxton is represented in its full thickness. The Ware formation, underlain by intrusive gneissoid granite, occupies the center of the anticline. The same sequence of formations would be expected on the west limb of the anticline and it does appear, but with a very greatly reduced thickness, for the Paxton formation, which has in the east a total thickness of 3300 feet, is represented in the west end of the tunnel by 900 feet. This reduction of thickness is borne out by the areal distribution indicated on the geologic map, in which the Paxton is shown as lensing out entirely toward the south.

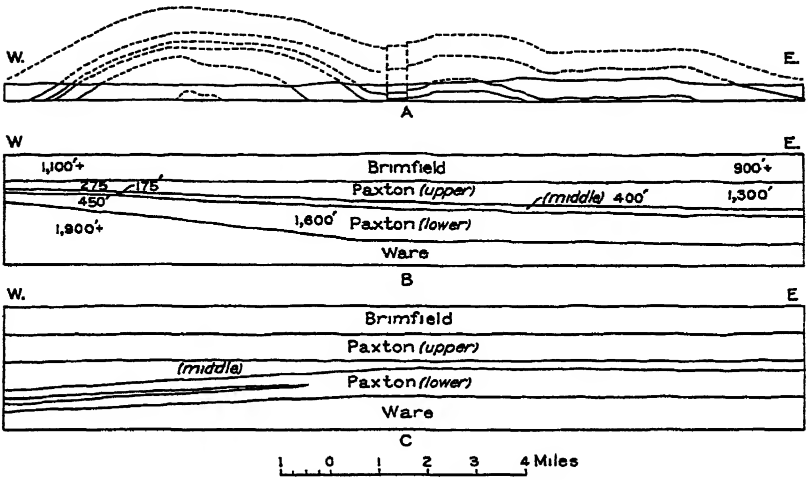

FIG. 24.—Sections illustrating two interpretations of the stratigraphic succession of the schist formations west of the Fitchburg granite. *A* is a structure section, with the eroded portions of the formations restored. *B* is a restored section, showing the thickness of the formations and the points at which they were measured. The biotite schist immediately west of the Fitchburg granite is correlated with the thick biotite schist at the western end of the section. The two thin feldspathic biotite schist members with the included biotite schist member at Shaft 8 are correlated with the much thicker members of the Paxton farther east. In *C* it is assumed that the thin formations at Shaft 8 represent the lower member of the Paxton and the thick biotite schist west of Shaft 8 represents a thickening of the middle member of the Paxton. The upper member of the Paxton and the Brimfield have disappeared by erosion or offlap, according to this interpretation.

The thickness of a metamorphic formation and, its relation to the original stratigraphic thickness, depends upon a number of factors. First, there is the difficulty of determining the present thickness. This is principally because of the numerous variations in the dip and strike of the foliation and because of lack of knowledge of the amount of displacement along secondary faults. Wherever the displacement could be meas-

ured, it was found to be in terms of a few feet or even a few inches. The relatively slight displacement, and the variation in direction of dip, probably make these structures compensate each other. With the exception of the biotite schist member of the Paxton, the thickness is only obtained once for each of the formations of the east side of the anticline. Second, it is not known to what extent the invasion of the igneous material has altered the original thickness, nor what the effect of recrystallization and movement has been.

However, it appears that the interpretation of thinning represented in Fig. 24*b* is the more simple and seems to conform more nearly to the facts. As the feldspathic member becomes thinner toward the west and grades into biotite schist, and as limestones are restricted to the western limb of the main anticline, it may be suggested that the source of the original sediments was to the east.

REGIONAL CORRELATION

Principles of Correlation

The problem of correlation concerns the establishment of the relation between the formations in the tunnel and those in the Worcester Basin, and especially that formation from which Carboniferous fossils were obtained. As no fossils have been obtained from the tunnel rocks, nor from the formations in the section east of the tunnel, it is necessary to use inorganic methods of correlation.

Possible criteria include (1) lithologic similarity, (2) mineralogical composition, (3) petrographic structure, (4) fractures, veins and secondary changes, (5) degree of metamorphism, (6) stratigraphic position and sequence, (7) structure and contact relations, and (8) igneous intrusions.

The Field Occurrence of Carboniferous Rocks

Carboniferous fossils have been obtained by Joseph Perry (*6*, *7*, p. 18) and David White (*8*), from a quarry pit in Worcester, due west of the north end of Wigwam Hill, and long known as the "Worcester coal mine." There are three distinguishable layers; the uppermost being a severely fractured black graphitic phyllite with much pyrite, the middle layer a massive, highly graphitic layer which Emerson and Perry have called graphite breccia; and a lower layer of firm, strongly phyllitic material. The layers contain numerous lenses and veins of quartz. David White found plant remains in pyrite concretions which he identified as Carboniferous, probably Pottsville.

The first problem is to determine the relation of this outcrop to the dark phyllite in the eastern end of the section. The large mass of phyllite touched by the section is north of this outcrop but not in line with the strike, but variation in strike may be expected and is not a serious obstacle in the correlation of the formation. The formation was not traced to the mass of phyllite to the north and the geologic map shows this locality as separated from the larger area by the phyllitic Oakdale quartzite. Therefore it is necessary to compare them on the basis of the principles mentioned above.

The two phyllites are lithologically similar, except for the much higher percentage of carbonaceous matter in the "Coal Mine" outcrop. The mineralogical composition, that is, the sericite and quartz, is the same, and the degree of crystallization and the microscopic structure is the same. Furthermore, the degree of metamorphism evidenced by the size of grain and the composition is practically the same. In addition, this outcrop is cut by quartz veins and contains quartz lenses which are in every way similar to that of the phyllite in the section. There appears to be no good reason, therefore, for separating this phyllite from that in the section, on the basis that it contains fossils or is a remnant of Carboniferous rock which lies upon very much older formations. It therefore seems reasonable to correlate the fossiliferous phyllite of the "Worcester coal mine" with the phyllite of the section. This is the conclusion of Emerson (*2*, p. 63) and there seems to be no dissenting opinion published.

The next problem concerns the establishment of the relation between the Worcester phyllite and the Oakdale quartzite. The contact is not exposed anywhere along the section presented in this paper but, in the zone near the contact, it is difficult to tell to which formation an outcrop belongs. The phyllite is strongly laminated with quartzite near the contact zone, suggesting that the contact is gradational. Therefore, it would appear that the phyllite lies upon the Oakdale quartzite in normal, transitional sedimentary contact. The phyllite also contains some layers of quartzite and the quartzite, in turn, contains phyllitic layers. A conformable contact between quartzite and phyllite was found on the west side of the anticline, on the east side of the reservoir.

The degree of metamorphism, the size of grain, the character of foliation, and the minor structures, are very similar. Both contain the same kind of quartz lenses and veins which have entirely similar relations to the foliation. Furthermore, W. O. Crosby (*1*), in his studies in the Wachusett tunnel on the east side of the Worcester Basin near the town of Clinton, found the phyllite intercalated with and grading into true

quartzite, thus establishing the original sedimentary relation of the two types in this area.

It thus appears that the Worcester phyllite conformably overlies the Oakdale quartzite. This is also the opinion advanced by Emerson and Perry (7, pp. 49, 127, 153). Judging from its physical conditions, it surely belongs to the same general age or at least is not separated by any metamorphic interval.

West of the Oakdale anticline, phyllitic quartzite, in every way resembling the Oakdale quartzite of the anticline, is exposed in the tunnel, and conformably overlain by phyllite or schist very similar to the Wor-

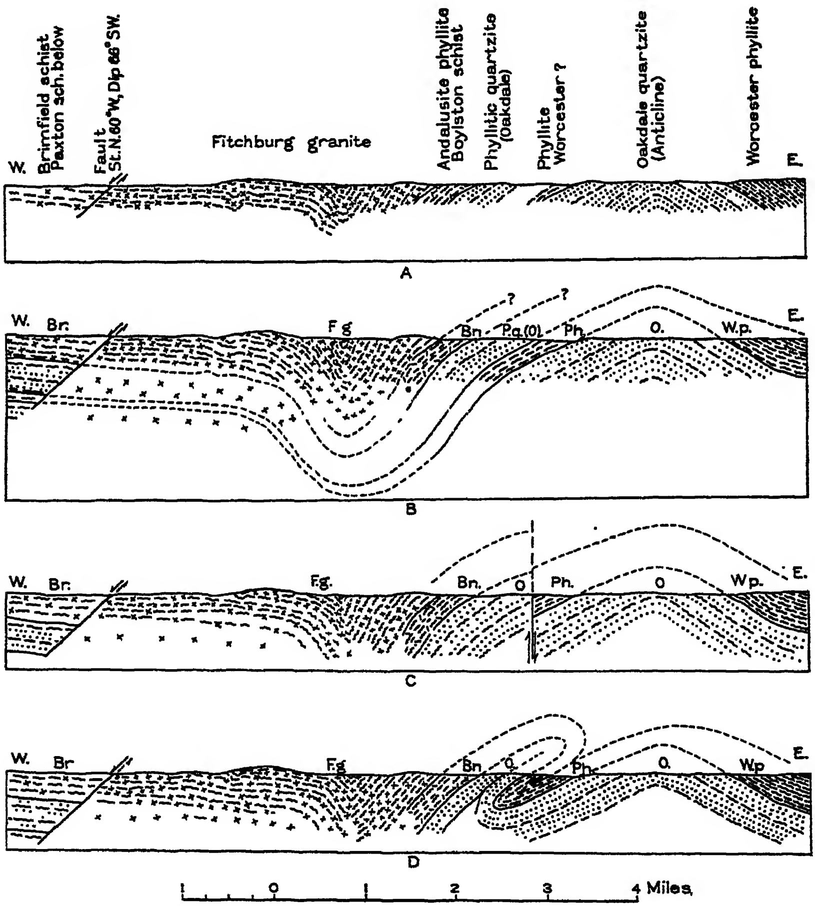

FIG. 25.—Three interpretations of the relations of formations in the eastern part of the section.

cester phyllite, but slightly coarser and containing andalusite, a contact effect. A break between the tunnel section and the Oakdale anticline, and the possible relation between these formations and those to the west of the granite, require interpretations which are shown by the sections in Fig. 25.

The observations are shown in Figure 25*a*. In Fig. 25*b* it is assumed that the formations west of the anticline all lie in conformable sequence and that they may be correlated through the granite with the schists to the west, the Boylston being correlated with the Brimfield, the phyllitic quartzite with the upper Paxton, the phyllite under the Wachusett Reservoir with the middle Paxton, and the Oakdale of the anticline with the lower Paxton. This would conform to the supposition that the formations of the Worcester Basin grade into the schist to the west.

In Fig. 25*c* it is assumed that there is a fault in the valley of Malden Brook between the phyllite exposed on the west limb of the anticline and the phyllitic quartzite in the tunnel. Assuming a down–throw to the east, the phyllite on the west side of the anticline corresponds to the Boylston schist and the phyllitic quartzite of the tunnel corresponds to the Oakdale quartzite of the anticline.

In Fig. 25*d* it is shown that the observed sequence of formations may be explained by assuming an overturned anticline and syncline. This explanation is proposed by Perry and Emerson (7, p. 49). The principal objection to this explanation lies in the lack of evidence of such folding and the fact that the formations are thinner in the isoclinal folds than they are in the open structures.

The fault hypothesis (Fig. 25*c*) offers the most simple explanation as it does not involve the bringing in of additional formations, changes of thickness, or complicated structures. Surface evidence of such a fault is lacking, but it is suggested by the arrangement of valleys to the north and south.

The north–south line along which the granite has mainly intruded, and in which there is vertical foliation, may represent a fault which separated the formations of the Worcester Basin from those to the west. The tunnel section does not reveal whether this is the true condition, but without negative evidence it may be considered.

An inquiry into the petrographic evidence for the correlation of the Worcester phyllite and the Boylston schist with the Brimfield, reveals that it would be entirely possible for a formation like the Boylston progressively to metamorphose into biotite schist, and near its contact with the granite it very closely resembles the biotite schist. However, the

Oakdale quartzite contains far less feldspar than the feldspathic schist, but it does contain carbonate which could account for the green bands in the Paxton. The correlation of these formations is doubtful.

THE AGE PROBLEM

Age of the Metamorphic Formations

The formations of the Worcester Basin, represented in the tunnel section by the phyllitic Oakdale quartzite and the Boylston schist, do not come in contact with the schists of the central and western parts of the tunnel section but, rather, with the Fitchburg granite. The Fitchburg granite penetrates both the Worcester Basin formations and the schists to the west. Therefore the granite is younger than both groups of formations. The granite is believed to be largely responsible for the metamorphism of the schists to the west. Consequently, the granite and the structures that have been brought about by the granitic intrusion cannot be used as evidence that the schists are much older than the formations of the Worcester Basin or are separated by any such interval as that between the pre-Cambrian and the Carboniferous. Therefore both groups could belong to the same general period.

However, the tunnel section does not reveal the exact relations between the two groups of rocks, so that this study does not permit a definite statement as to the age of the schists of the central and western parts of the tunnel section, but does demonstrate that they can be of the same general age. The greater degree of metamorphism and injection of the schists suggests that they may belong to an older series separated from the Carboniferous formations by a fault represented, in part, by the mass of the Fitchburg granite; but definite proof is lacking.

Age of the Igneous Rocks, Dikes, and Veins

The pegmatite and granite masses are of the same general character throughout the tunnel, and no examples of one granite cutting another have been found. Therefore, there is no evidence that all the granites and pegmatites of the tunnel do not belong to the same general period of igneous invasion. The pegmatite and granite in the Oakdale quartzite, near the granite contact, and in the Boylston schist, are also entirely similar to those in the schist. Therefore, if the Carboniferous age of the Oakdale quartzite is regarded as established, the igneous rocks are of Carboniferous or later age.

The diabase dike is, therefore, of post–Carboniferous age and probably belongs to the same period as the diabasic intrusions in the Triassic sediments in the Connecticut Valley.

The fact that some of the pegmatite dikes in the granite have sharp borders and even joints parallel with them, shows that they belong to the very latest stages of igneous activity, and that some of the joints began to be formed at the close of this period. The extreme rarity of pegmatite veins or dikes sharply cutting across the foliation, or parallel to any of the joint systems, demonstrates that jointing began definitely after the pegmatitic phase of igneous activity. Quartz veins occur along joints and probably belong to, or closely follow, the period of joint formation. The quartz is nearly always found to be shattered—indicating subsequent movement.

Age Relationships of Joints, Faults, and Crush Zones

Although some 2000 of these structures were examined throughout the tunnel, no definite evidence of relative age among the various systems was discovered. It seems quite probable that the major systems were initiated at the close of the igneous activity, by the continued action of the regional forces involved in the igneous invasion. It is also very probable that there have been subsequent movements producing new and different joints, and renewed movements on preexisting fractures. Though none of the major joint systems was observed to continue through the post–Carboniferous diabase dike, a condition which suggests that they antedate the dike, it must be remembered that the dike rock is quite different in character, and full of cooling cracks which would take up any subsequent movements. Consequently, no precise determination of the age of these structures is regarded as possible.

SUMMARY

It is believed that this paper makes the following contributions to the geology of Central Massachusetts.

(1) A structural geologic section 14.2 miles long, taken directly across the strike, is presented. It is based upon the continuous section provided by the tunnel excavation and is extended into the Worcestor Basin, upon evidence of surface outcrops. It is the first detailed section of this area to be published.

(2) The Brimfield and Paxton schists are redefined and given significance as formations rather than as rock types.

(3) A part of what was formerly called Brimfield schist has been designated as a separate formation, the Ware, because it was found to lie below the Paxton schist.

(4) The Fitchburg granite was found definitely to have penetrated both the Boylston schist and Oakdale quartzite, and the schists to the west as well, so that the formations of the Worcester Basin cannot be separated from the schists in, or west of, the granite, on the basis of the granite intrusion. The exact relations between the two groups are not brought out because the granite intervenes between them. Therefore, it is shown that the Brimfield, Paxton, and Ware formations may be of Carboniferous age but do not necessarily belong to that period. The greater degree of metamorphism and igneous intrusion of the schists west of the granite, suggests that they belong to a different and possibly older series.

(5) Alternate explanations of the relations between the andalusite schist and phyllitic quartzite of the tunnel section and the Oakdale quartzite and Worcester phyllite east of the tunnel are offered.

(6) No basis has been found for separation of the Hubbardston and Fitchburg granites on evidence supplied by study of the tunnel excavations.

(7) Data on nearly 2000 joints, faults, and veins have been analyzed, and interpretations suggested.

(8) The foliation of the schists has been shown to be parallel to bedding and formational contacts.

(9) The Paxton formation has been interpreted as becoming thinner toward the west, suggesting that the source of the original sediments was to the east. The feldspathic character has been emphasized.

(10) Contacts have been established accurately in the tunnel, and projected to the surface, locating them more accurately than has been done previously. This is especially true of the feldspathic biotite schist between Shafts 6 and 7, which is not shown on the Geologic Map of Massachusetts. This detailed information should permit a much more accurate surface mapping of this area than has heretofore been possible.

BIBLIOGRAPHY

CROSBY, W. O.

(*1*) 1898. Geology of the Wachusett Dam and Wachusett aqueduct tunnel of the Metropolitan Water Works in the vicinity of Clinton, Massachusetts. Technology Quarterly, XII, pp. 68-96.

EMERSON, B. K.

(*2*) 1917. Geology of Massachusetts and Rhode Island. U. S. Geol. Survey Bull. 597.

Metropolitan District Water Supply Commission

(*3*) 1927. Annual Report of for Year Ending Nov. 30, 1927. The Commonwealth of Mass. Public Doc. No. 147, pp. 24-25.

(*4*) 1928. Annual Report of for Year Ending Nov. 30, 1928. The Commonwealth of Mass. Public Doc. No. 147, pp. 18-20.

(*5*) 1929. Annual Report of for Year Ending Nov. 30, 1929. The Commonwealth of Mass. Public Doc. No. 147 (in press).

PERRY, J. H.

(*6*) 1885. Amer. Jour. Sci. 3rd ser., XXIX, p. 157.

PERRY, J. H. and EMERSON, B. K.

(*7*) 1903. The Geology of Worcester, Massachusetts, pp. 1-166.

WHITE, DAVID.

(*8*) 1912. Age of the Worcester Phyllite. Washington Acad. Sci. Jour., II, p. 114.

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INDIANS OF THE PARANÁ DELTA, ARGENTINA *

By SAMUEL KIRKLAND LOTHROP

CONTENTS

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PREFACE

This study presents the results of an archeological expedition jointly supported by the Museum of the American Indian, Heye Foundation, and the Museo de La Plata. The undertaking was financed by Mrs. Thea Heye. In 1924 Director and Mrs. Heye visited the Argentine and made the necessary arrangements with Dr. Luis Mariá Torres, while in 1925 three archeological sites in the Paraná delta were excavated as herein described. The personnel consisted of Antonio Castro from La Plata Museum, R. W. Lothrop, Sergeant Constantino Martínez, the writer, and workmen from the vicinity.

The Thea Heye–La Plata Expedition accomplished the excavation of three ancient villages and burial grounds, which are located in Fig. 6. Work commenced on the banks of the Arroyo Malo near the Canal Arias, where Guaraní remains were encountered. We then undertook excavations on the south bank of the Paraná Guazú river, about a mile west of the Paraná Miní, where our finds represented the Chaná–Mbeguá or possibly the Chaná Indians. Finally we unearthed, near the south bank of the Río Luján, vestiges of the Guazunambí, apparently a subtribe of the Querandí Indians.

As we found at the first and last sites several objects of European manufacture, the remains must date, at least in part, from the period between the original discovery and the extermination of the natives toward the close of the seventeenth century. At the second locality no exact indications of age were forthcoming, but the artifacts recovered so closely resemble those from post–Columbian sites that any great chronological separation seems utterly improbable.

In making acknowledgments I wish to thank Mrs. Heye for her generous financial support and Director Heye for arranging the preliminary details with Dr. Torres. I must also express my appreciation of the unusually laborious task of restoration, carried out chiefly by Mr. J. Bush, who has made available for study a very badly shattered collection.

During our stay in Argentina we received many courtesies. Dr. Torres placed the facilities of the Museo de La Plata at our disposal, while Dr. R. Lehmann–Nitsche and Señor Pablo Gaggero aided us in getting the work under way. I am also exceedingly grateful to Argentine scholars for sending me copies of their publications, without which it would not have been possible to prepare this volume, and for such courtesy I wish to thank Dr. R. Lehmann–Nitsche, Prof. F. F. Outes, Prof. Antonio Serrano, Dr. L. M. Torres, and Prof. M. A. Vignati.

While work was in progress we received constant help and advice from Señor Eugenio Tricerri and from his wife and children, whose generous hospitality and kindness we shall always remember with gratitude. We are also indebted to Mr. Kenneth Apollonio of Buenos Aires, who gave much time and energy to unraveling necessary details.

La Plata Museum, according to agreement, received from our collections certain unique specimens. In addition, we deposited with that institution a large dugout canoe, all animal and all human bones, and a representative collection from our third excavation. As Dr. Torres and Señor Gaggero had already dug in portions of the other two sites, our finds for the greater part duplicated material already exhibited at La Plata. This account of the remains is based on material now in New York.

Our illustrations have been prepared by Mr. Louis Schellbach and Mr. W. C. Orchard of the Museum staff, and by Mr. William Baake. Mr. Schellbach has drawn all the maps.

INTRODUCTION

The great tidal estuary known as the Río de La Plata, more than 150 miles wide at its mouth, is cut by south latitude 35°, and therefore lies approximately at the latitude of the southern tip of Africa. Two vast river systems, the Uruguay and the Paraná, pour their waters into the Río La Plata. Of these, the former rises in the Brazilian state of Santa Catherina, less than 100 miles from the coast, at about south latitude 28°. Its limpid waters, forming successively the boundary between Brazil and Argentina, and Uruguay and Argentina, flow south-southwest and then nearly due south along the Purple Land of the *Banda Oriental* to the Río La Plata.

The Paraná rises far to the north, at about south latitude 16°30′, near the federal district destined to contain the future capital of Brazil. Known successively as the San Marcos, Paranahyba, Alto Paraná, and Paraná, it runs in a south-southwesterly direction between Brazil and Paraguay. It then swings westward between Argentina and Paraguay; entering the territory of the former, it flows south and then southeast to the R. La Plata. The Uruguay, passing through rocky lands, boasts clear and clean water, and it is the Paraná, turbid and silt-laden, which causes the muddiness of the misnamed River of Silver. Hundreds of miles above its mouth the Paraná begins to deposit its burden of silt to form innumerable and ever-varying islands, while from the city of Santa Fé downstream the eastern bank is a wide alluvial plain, swampy in character, cut by a thousand arroyos and intersecting canals. Opposite Constitución, about 200 kilometers from the R. La Plata, the Paraná splits into two main branches, and from here to the river's mouth extends the delta. Its nature and extent are revealed in the accompanying maps (Pl. II and Fig. 6). Both main branches of the river, called the Paraná Guazú and the Paraná de las Palmas, cut the lower part of the delta, where they are connected by navigable cross-streams such as the Paraná Miní and the Carabelas. North and south are parallel rivers, the Paranacito and the Luján, linked to the delta country by intercommunicating arroyos and recently constructed large canals. To enumerate even the important islands, creeks, and canals of the delta would be a long and tedious task, not pertinent to the present inquiry. Suffice it to say that today as in aboriginal times all communication, except in restricted areas, is water-borne.

According to current opinion, in Tertiary times the Argentine Pampas formed a great inland sea, as is shown by the numerous marine shells and infusoria to be found in many places. With the emergence of the present plain, the Paraná emptied itself into a shallow arm of the ocean, which presently became a brackish swamp. Still more recently the vast load of detritus discharged by the overloaded waters of the river has created a level plain a few feet above the normal water level.

The constructive energy of the river can be judged from the studies of Argentine engineers who estimate that the drainage basin covers not less than 2,574,000 square kilometers, and that the flow through the Guazú and Bravo branches alone averages 194,400 and 226,800 cubic feet per second. The deposit of detritus reaching the R. La Plata, in addition to what has settled in the delta, is said to be about 60,000,000 cubic meters, or almost 2,000,000,000 cubic feet annually (*225*, p. 8)* In the Paraná, then, we have one of the greatest constructive fluvial forces known today, and it is the Indian inhabitants of these new–built lands who are the subject of this study.

The vegetation of the Paraná delta has undergone a complete change in recent years, for the palms, ceibo, algarroba, quebracho, and laurel which once flourished have been cut to serve as fuel in Buenos Aires. In their stead the inhabitants grow fruit trees, and there also exist great artificial forests of willows and poplars destined for firewood. The rich soil and hot summer climate of the delta induce a surprisingly rapid growth, not only of trees but of underbrush, which in places is almost impenetrable. Tree mosses give a gloomy character to existing remnants of primeval forests. Dr. Torres recognizes three zones of vegetation in the delta, but these are of botanical rather than ethnologic interest.

The fauna of the delta includes jaguar, deer, otter, carpincho, and seal. The common birds are ducks, geese, swans, flamingos, hawks, owls, swallows, doves, and plover. Fish, which are exceedingly common, include pejerrey, dorado, and manduví. Six varieties of clams were eaten by the aborigines.

The climate is varied. In summer the heat, although less than in Buenos Aires, is intense, and life in the open is made miserable by hordes of gnats and mosquitoes. In winter the nights are long, and there are hard frosts. By the middle of June we found it advisable to abandon work because fragile objects could be taken from the frigid ground only

* Throughout the present paper the numbers in italics enclosed by parentheses refer to works similarly designated in the Bibliography.

during a short period in the middle of the day. The effects of temperature extremes, both hot and cold, are intensified by the humidity.

The most peculiar characteristic of the delta, apart from its flatness and its extent, are the floods. These are of two kinds: first, those of a devastating nature, dependent on rainfall in regions far to the north, and fortunately of rare occurrence; secondly, floods of local character, which occur fairly frequently. The local floods depend on the strength and direction of the wind. When it blows from the east or southeast the waters of the R. La Plata are backed up against the mouths of the Paraná with the result that the surface often rises many feet in a few hours, and large areas may thus be inundated directly from the creeks and canals. Furthermore, the humid soil yields readily to underground flow from the never distant streams, so that the water-table rapidly rises to or over the

FIG. 1.—Flooded urn burial, Arroyo Malo.

surface of the land. Latzina's record of wind directions, quoted by Torres (*225*, p. 12), reveals 16.7 percent. from the east and 13.4 percent. from the southeast. How many of these winds might cause floods would depend on imponderable factors, such as wind velocity, previous height of the water, height of the land at any given spot, etc.

Floods of local nature proved a constant difficulty for the successful carrying out of excavations. Both skeletal material and pottery often were too delicate for removal from the ground until cleared and dried *in situ;* yet when they were ready for extraction all too often the rising water-table submerged everything and caused days of delay. Specimens packed for shipment could be protected from rain, but not always was it possible to carry the boxes to staging before the waters rose. At times the only practical method of getting out burials was by bailing continually

while the mud was searched for fragments, the difficulty of which task may be gauged from the flooded burial urn in Fig. 1. A particularly unfortunate effect of the water was that owing to the softness of the ground almost all pottery vessels had been broken into myriad fragments by the deeply penetrating hoofs of horses and cattle.

Of the great floods, which come every ten or fifteen years, happily we saw nothing. They originate in the far interior and depend on simultaneous and heavy rainfall over large areas. In readiness for them, the modern houses of the delta stand on tall stilts, but even so the unfortunate inhabitants may be forced to the roofs, there perhaps to cling in hunger for days, while they pray that the foundations will withstand the rush of waters and the battering of heavy débris.

TRIBES OF THE LOWER PARANÁ AND LA PLATA RIVERS

The Indians who once inhabited the delta of the Paraná, the adjacent shores, and the banks of the R. La Plata fall into three categories: (1) On the islands at the mouth of the Paraná lived Guaraní Indians, relatively short in stature and thickset, cannibals, agriculturists, fishermen, and hunters. (2) On each shore of the R. La Plata lived the Querandí and Charrúa, primarily nomadic hunters and fishermen, ignorant of agriculture, tall, and warlike. (3) Upstream from the Guaraní in the delta country there dwelt a number of tribes, intermediate in culture, such as the Chaná, Timbú, and Mbeguá. Physically and linguistically the relationship of this group seems to have been with the Charrúa and the Guaycurú to the north; culturally they show much the same basic pattern, but they had acquired certain Guaraní traits, such as permanent villages and agriculture. The nomenclature, geographical distribution, and linguistic affiliation of all these groups are mixed and uncertain, and must be discussed in some detail. We shall also briefly review the sources of our knowledge.

HISTORICAL SOURCES

It is the claim of historians that no great movement of population has been so faithfully recorded as the discovery and colonization of the New World by the nations of Europe. This may indeed be true, but in the case of even the most epoch-making events (such as the first voyage of Columbus or the conquest of Mexico by Cortés) the accounts written by actual eye-witnesses are short and incomplete; and often they were set down many years after the undertakings had occurred—when time had enhanced their importance but had romanticized them in the memory of the historian. If this happened with spectacular and successful ventures, we need not be surprised that the less lucky expeditions received but scant and inaccurate mention from contemporary writers. And the Spanish succeeded on the River Plate only after many failures. Hence our knowledge of this region and its inhabitants comes from accounts which are short, lacking in detail, and contradictory. We list the important expeditions of discovery, pacification, and colonization, as well as the outstanding literary sources arising therefrom.[1]

1.—JUAN DE SOLIS. This celebrated pilot first explored the basin of the R. La Plata in the year 1516 and gave his name to it for some years to come. Unfortunately for him, he chose to land in the presence of natives

[1] Exact references will be found under the authors named in the bibliography.

and fell before their arrows. Presumably they were Guaraní, because his body was eaten with those of other victims, in full sight of his ship's crew. We have encountered no literature of anthropological interest arising from this ill-starred voyage.

2.—SEBASTIAN CABOT. Cabot left Spain with the title of "Captain General of the Spicery Fleet" and with instructions to proceed to "Tarsis, Ophir, and Oriental Cathay" by way of the Straits of Magellan. However, he put in at the Río de la Plata and ascended the Paraná as far as the Río Carcarañá, where he erected houses in order to cure his ailing crews. While there he obtained notice of great wealth in gold and silver [2] to the west, and even secured samples which the natives of the locality had obtained by trade. Since this wealth appealed to him more than the arduous passage of the southern straits where the *armada* of Loysa had recently come to grief, he decided to fortify his village of twenty houses, and to enrich both himself and the Spanish Crown without further voyaging. To this end he dispatched an embassy overland to the west under the command of Captain Fransisco César,[3] whose name lives in the fabulous city of *Los Cesares*, the Cibola of the southern continent, while Cabot himself proceeded upstream in an attempt to reach the reported mines by water. A small guard maintained his fortress, called Sancti Spiritus, which stood near the present town of Gaboto. Ill fortune followed him, however, and he found not gold but stout resistance, so that after obtaining a little silver [4] he was forced to return to Sancti Spiritus, which was stormed by the natives soon afterward, during the absence of Cabot with the main fleet. Hence Cabot returned to Spain with some few samples of gold and silver, as well as the tale of wealth which Captain César reported to have seen during his overland journey. In Spain numerous lawsuits were brought against Cabot on account of the rigors of his discipline,[5] and the testimony resulted in descriptions of his voyage. Furthermore, Luis Ramírez, one of the pilots, wrote a long letter to his father in 1527, and this document fortunately has survived. In addition, the royal geographer, Alonso de Santa Cruz, was present and has written

[2] Hence the name *Río de la Plata*, River of Silver.

[3] For a fuller account of this interesting expedition see Medina, 1908, Vol. I, pp. 234-37 and elsewhere; also Bayo, 1913, and Latcham, 1929a. In 1533 Fransisco César was the lieutenant of Pedro de Heredia on a most successful treasure hunt in the Sinu region of Colombia. He later served under Vadillo, who discovered the Cauca valley. The death of César caused the expedition to terminate.

[4] Del Techo (1732, p. 639) writes that this silver was not of native origin but was the plate found in the effects of the Portuguese expedition from Brazil, whose leader, García, was slain in Paraguay. Charlevoix claims that the greater part of the treasure was Indian handiwork.

[5] The testimony given in this litigation is printed in Medina, 1908, Vol. II.

briefly in his *Islario,* and he communicated many more facts to his friend Gonzalo Fernández de Oviedo y Valdes, the royal historian.[6]

3.—Diego García de Moguer. Before dispatching Cabot to the Spice Islands, the Spanish Crown had sent a fleet under command of García to colonize the Río de la Plata, but owing to the routes followed, Cabot reached that region first. The relations between the two commanders were not cordial. García, like Cabot, ascended the river as far as Paraguay, and ultimately returned to Spain. The best accounts of his voyage come from his own *Relación* and Oviedo's *Historia.*

Fig. 2.—Attack on Corpus Christi by the Timbú. (After Schmidel.)

4.—Pero López de Souza. In 1531 the Portuguese under the brothers López de Souza explored the southern coasts of Brazil and Uruguay, and finally entered the R. La Plata estuary. Pero's diary is an important source for knowledge of the Charrúa and Chaná–Mbeguá tribes.

5.—Pedro de Mendoza and Diego de Irala. In 1536 an imposing *armada,* consisting of fourteen ships and 2650 men under Pedro de Mendoza, reached the R. La Plata and founded a town on what is now the

[6] "Diré alguna cosa con brevedad de lo que entendí del camino, en especial de Alonso de Sancta Cruz y del capitan N. de Rosas, que son hombres hijosdalgos, y de otras personas que le vieron." (Lib., XXII, cap. II.)

site of Buenos Aires, as well as a fortress called Corpus Cristi, or Buena Esperanza, on the Paraná some leagues below Cabot's ill-fated settlement (Fig. 2). The complicated course of subsequent events does not directly concern us. Suffice it to say that the Spaniards suffered great hardships at the hands of the Indians and from hunger. Finally Mendoza set out for Spain, dying on the way, and Irala, who had assumed command, abandoned Buenos Aires and moved the settlement to Asunción in Paraguay. There, Alvar Nuñez Cabeza de Vaca succeeded him as leader, and for nearly forty years the Spaniards left the lower Paraná in peace. These events and the state of the Indians at that time we know chiefly through the pen of a German adventurer, Ulrich Schmidel, who spent many years in the country but who wrote his account long after he had returned to Europe.

6.—Juan de Garay. In 1573 Juan de Garay descended the river from Asunción to found the town of Santa Fe on what is now the site of Coyastá, whence it was transferred to its present situation in 1660. In 1580 Garay resettled the town of Buenos Aires, where he defeated a coalition of the neighboring Indian tribes. With these events, the period of colonial administration begins, although the exploration of the remoter parts of the country and the subjection of the inhabitants was not completed until long afterward.

Two important histories of the discovery and Spanish conquest were written if not by eye-witnesses at least by men who knew the country at a time when many of the original conquerors still lived. One of these writers was Barco Centenera, a priest from Estremadura, who arrived in the Argentine in 1573, and composed an epic poem which follows the course of events to the year 1581. His work shows him to have been a credulous and prejudiced person, but it has distinct historical value. The other writer was Ruiz Díaz de Guzmán, who was born in Paraguay in 1554.

During the colonial epoch various attempts were made by the Franciscans and, more especially, by the Jesuits to Christianize the natives. The Jesuits first entered the country in 1586 and were finally expelled in 1767 (*78, 181*). The main efforts of the missionaries centered on Paraguay, where the ruined remains of their churches still stand, but sickness soon exterminated the neophytes gathered in missions along the lower Paraná, while the unruly Uruguayan tribes stubbornly resisted both ecclesiastical persuasion and the force of Spanish arms. As a result of clerical enterprise, however, there exists a large body of literature dealing with the natives, written by educated and well-informed if at times unsympathetic

observers. Among the most important we should mention the works of Del Techo, Xarque, Ruiz, Dobrizhofer, Charlevoix, Lozano, and Falkner. Their books recapitulate and to a certain extent amplify the earlier records, and at the same time give us glimpses of Indian tribes at the moment of various *entradas*. However, like the sixteenth century documents, the missionary literature contains much evidence of an enigmatic, conflicting, and unsatisfactory nature.

At the end of the eighteenth and beginning of the nineteenth centuries we come to the works of men who personally knew the surviving Indians and who described them from the viewpoint of science. The outstanding writers in this group are Falkner, Azara, and d'Orbigny, and we should add the name of Hervas, who, while personally unacquainted with the natives, classified their languages from missionary manuscript material, much of which he obtained from Joaquín Camaño. D'Orbigny's grouping of tribes in southern South America is essentially that of modern anthropological students, although the system on which he based it must be regarded as unsound.

These are the main historical sources for study of the natives of the lower Paraná and R. La Plata. In spite of the fact that they have been freely utilized by Argentinian scholars in recent years, the volumes in which they appear are rare and in some cases impossible to obtain in the libraries of the United States. Hence it has seemed wise to reprint certain portions of them which bear directly on the Indians. This has been done in our Appendix I, where, so far as is possible, the material has been segregated by tribes and arranged in historical sequence.

In preparing the following account of the inhabitants of the Paraná delta, we have been guided by two principles. In the first place, as the picture which can be drawn of any given tribe is incomplete, we shall describe all the tribes of the neighborhood, in order to give as adequate as possible a background for study of the archeological remains. Secondly, when historical data are conflicting, we shall not attempt to slur or conceal the fact, nor endeavor to reconcile them beyond a point fully warranted by available evidence.

Names of Tribes

The difficulties in tribal nomenclature are illustrated in the accompanying table. It will be observed that, apart from the orthography, early authorities such as Ramírez, García, and Oviedo are in essential agreement. This is perhaps to be expected for the individuals named were of the same nationality and no doubt were personally acquainted with each

TABLE I.

Ramírez (1527)	García (1527)	Oviedo (Ca. 1530)	Schmidel (1562)
Guaranies (or Chandris)	Guaranies	Guaranies	
Quirandies	Carandies	Guarandos (or quicanys)	Carendies
	Charruases	jacroas	Zechurias
Chanaes	chanaes	Chanaes (or Janaes)	
Beguas		Beguaes	
		Janaes bequaes	
Chanaes tinbus	ch anes atembures	Janaes timbus (or chanastinbus)	
timbús	Atambies	tinbus	Tyembus
cacarais	caracaraes	caracaraes	
			Curanda
			Gulgaises

Nomenclature of Tribes of the Río La Plata and Paraná.

other. At the same time, these names are confirmed in two cases by the Portuguese Pero López de Souza,[7] who presumably was not in contact with the Spanish explorers.

Ramírez, García, and Oviedo mention the Chaná, Mbeguá and Timbú as well as tribes called Chaná-Mbeguá and Chaná-Timbú. These double names appear in no other early writings except López de Souza, who speaks of the "beguoaa chanaa." Hence it seems a question whether three or five tribes are involved. It might well be argued that the later writers represent a period when the country had been settled, and therefore were in a better position to know just what tribes existed. On the other hand, small tribes may have been exterminated, or may have coalesced with their neighbors.

A second problem is put by the names in the *repartamiento* of Indians, made after the second founding of Buenos Aires in 1582; most of the "nations" on the list are mentioned nowhere else. Many other Spanish accounts of natives in other lands are confusing because the names of chiefs and of tribes have not been clearly distinguished. But, in this case, the chiefs are named as well as the tribes. Probably then this list contains subtribes of the larger groups recorded in other documents.

A third problem arises from such tribes as the Bohané, Yaró, Martidané, Minuané, and Güenoa, for, while extant and known to the missionary writers, they received no mention from the earlier chroniclers.

[7] See Appendix I, p. 209.

TABLE I

Repartamiento of 1582	Barco Centenera (1602)	Ruidíaz de Guzmán (1612)	Encomiendas of 1678	Lozano (1745)
Guaranis de las Islas	Guaranies	Guaranies	Guaranis	Guaranies
	Cherandies	Querandies	Quirandis	querandies (or Pampas)
	Charuahas	Charruas		Charruas
Chanas			Chanas	Chana
Meguay	Beguaes		Bagual	beguaes
Curumeguay (?)				
	Timbues	Timbúes		timbues
		Caracarás		caracaras
Calchilaces (?)	Chiloaças	Quiloazas		quiloases
			Colastines	colastines
Dulluseembes				martidanes
Lajae[1]				guenoas (or Minuanes)
Lojae–Emelaguaé	Tabichaminis (?)			guacunambis
		Yaros		Yaros
Yoto Serebes	Mohamas[2]	Mahomas[3]	Mabonas	mohamas[4]
Llosumbes	Epuaes		Epuaes	epuaes
Locultis	Calchines	Calchinas[3]	Galchines	calchines
Cubuje	Agazes	Agaces[3]	Agaces	agases
	Nogoes		Nogoes	nogoes
Denocunalacos			Sanasines	sanasines
Ajay	Maures		Maures	maures
Cononii	Tecos		Tecos	tecos
	Sansones		Sansones	sauzones
Alacas	Mogoznaes	Mogolas[3]	Mogoznaes	mogonas
Secti	Naues		Naves	naves
Caltis	Mepenes		Mepenes	mepenes
	Quilmes			abipones
Curucá	Mocoreta etc.			calchaquis

Nomenclature of Tribes of the Río La Plata and Paraná.

NOTES ON TABLE I

[1] Except for this list there is no mention of these "nations." They evidently are subtribes, as the names of their chiefs are given.

[2] This list includes tribes moved from their original homes by the Spaniards and also peoples who lived north of Santa Fe.

[3] These, according to Díaz, were originally tribes of Paraguay living south of the Guaycurú.

[4] This list includes tribes found in the "Provinces of the Rio de la Plata . . . at the time of the conquest" (vol. I, p. 380), as well as other groups mentioned elsewhere by Lozano as inhabiting the lower Paraná. It is evidently based on Barco.

Possibly there took place a change in nomenclature, and we should see in these groups the descendants of the vanished Chaná–Mbeguá and Chaná–Timbú of the discoverers. One definite instance of such a change in name has been recorded by Lozano, who states that the Güenoa and Minuané were one and the same tribe. Also, the name Querandí changed to Pampas.

The origin of tribal names given by the early explorers is very uncertain, and often there is no way of deciding whether the names that have come down to us are what a group of natives called themselves or what their neighbors called them. It is also possible that a tribe might be named by the Spaniards from some frequently repeated phrase. In several instances, however, the names evidently come from the Guaraní tongue, in which they have appropriate meanings, e. g., the Querandí are the "people who possess grease." This source of tribal nomenclature no doubt was due in part to the Guaraní colony at the mouth of the delta, while it is probable that the various expeditions carried with them Guaraní interpreters obtained along the coast of Brazil.

Names which came into use some time after the Conquest, such as Yaró and Güenoa, probably are what the various tribes called themselves. At any rate, there seems to be no obvious reason for deriving them from the Guaraní tongue.

Distribution of Tribes

If the very names of the Paraná tribes are uncertain, to assign them to definite localities is an even more difficult problem, which we have attempted to solve in pl. ii. The conflicting historical sources on which this map is based have been brought together in Appendix ii. We may point out that complete geographical knowledge of the delta region has only been obtained recently and the early writers are extremely vague in their descriptions of a region which lacks prominent landmarks. Hence it is impossible to lay down the exact boundaries that must once have existed and we have not attempted to do more than indicate the approximate area occupied by each group.

Linguistic Relationships

The only survivals of the languages spoken by the tribes we are discussing consist of three Charrúa words (*206*), a Güenoa catechism (*170*), a Chaná grammar,[8] certain place–names and the names of chiefs (*56, 191*). It is evident from the earliest historical sources that various dialects which the student of today might group together differed a good deal from one another. For instance, Ramírez (*189,* appendix I, p. 170)

[8] Published by Lafone Quevedo (1897) and Torres (1911).

regarded Timbú, Chaná–Timbú, Mbeguá, Chaná, and Caracará as distinct, while Oviedo (*180*, Lib. XXIII, cap. XII) declared that Timbú, Chaná–Timbú, Mbeguá, Caracará, Querandí, Guarandí, and Charrúa were unrelated.

On the other side of the picture we find certain tribes definitely linked. Thus Oviedo (*180*, Lib. XXIII, cap. V) stated that Chaná–Mbeguá and Chaná–Timbú were one tongue, while Schmidel (*202*, p. 15) linked Timbú, Corondá, and Quiloaza, and Hervas (*82*, Vol. I, p. 187, note) grouped Charrúa, Yaró, Bohané, and Minuané–Güenoa. Schuller (*205*, *206*), on the basis of the three surviving Charrúa words and the Chaná grammar, regards both as belonging to the Guaycurú linguistic family, to which he adds all the other tribes under consideration except Querandí and Guaraní. Outes (*170*) has demonstrated the linguistic unity of Chaná and Güenoa. Rivet (*193*) somewhat doubtfully attaches the Querandí to the Guaycurú, but, like Brinton (*34*) and Chamberlain (*45*), he groups the tongues of the Paraná delta and western Uruguay separately under the title "Famille Tšarrúa." To the present writer it seems that Schuller's hypothesis of a continuous chain of Guaycurú dialects extending down the Paraná and into Uruguay cannot be sustained solely by the scanty linguistic data available, but the cultural continuity among the peoples involved suggests that he is correct in his belief.

The Guaraní spoken in the Paraná delta has survived to this day in the form of numerous place-names, which indicate that the language did not differ markedly from what we may call the classical form of that tongue as recorded by the Jesuit missionaries. Or possibly the place-names themselves have been modified to accord with what has come to be regarded as classical Guaraní.

Detailed Description of Tribes

GUARANÍ

The "Guaraní de las islas," also called Chandris or Chandules, inhabited the southern side of the Paraná delta[9] from the islands of the Río de la Plata (*95*, *175*, *53*, p. 204) to within a dozen leagues of the Río Carcarañá.[10] Thus they constituted the southernmost enclave of a very large and widely distributed linguistic family. Although mentioned by all the early explorers, surprisingly little description of them is available, and they appear to have become extinct before the end of the seventeenth century. It is therefore impossible to make detailed comparisons between this group and their kinsmen to the north.

[9] Oviedo, Lib. XXIII, cap. II. Archeological evidence places the Guaraní south of the Paraná de las Palmas and north of the Luján.

[10] Sebastian Cabot, in our Appendix I, p. 200.

Looking at South America as a whole, it seems that each of the three great linguistic stocks was characteristic of one of the three great drainage basins. Thus the Arawak apparently centered on the Orinoco, the Carib on the Amazon valley in the region between the Xingu and Tapajoz, and the Tupi–Guaraní on the territory between the Paraguay and upper Paraná (*193*, pp. 644, 650, 659, 687). In the course of time, however, various groups have changed their habitat, so that the different stocks became not only widely distributed but greatly intermingled.

The main line of migration of the Tupi–Guaraní in prehistoric times was eastward to the Atlantic littoral, thence northward to the Amazon, westward up that drainage basin, and finally up various tributaries, especially on the southern side. In addition, after reaching the Atlantic coast, certain tribes, such as the Arachanes,[11] pushed southward until they came in contact with the Charrúa. Possibly the Guaraní of the Paraná delta reached their territory by a similar route; more probably they descended the river from their original home in Paraguay. The similarity of archeological remains from the delta to those from the upper Paraná indicates that the separation had taken place not long before the coming of the Spaniards.

Tupi–Guaraní speech was adopted by European settlers, traders, and missionaries over a very wide area in South America, for dealing with the Indians. The Cainguá dialect today forms the basic language of Paraguay, and there is a large body of modern literature printed in it. In the same way the Tupi dialects have become incorporated in the so-called *lingua geral* now spoken throughout the Amazon valley in particular and Brazil in general. Thus, in eastern South America, Tupi–Guaraní holds the position occupied by Quichua and Araucanian on the west coast and by Nahuatl in Central America.

To return to the Guaraní of the Paraná delta, they are described as cultivating maize and calabashes,[12] and hence they mark the southern limit of agriculture on the eastern side of the continent. In addition, they ate much fish, which they dried in the sun,[13] and, when they could get it, they consumed human flesh.[14] Lozano [15] describes them as "very

[11] "Mas de veinte mil indios guaranies que llamaban *Arachanes*, no porque en las costumbres é idiomo se diferenciasen de los demas de aquella nacion, sino porque traian revuelto y encrespado al cabello: era gente bien dispuesta, corpulenta y muy bellicosa, ejercitando de continuo las armas con la nacion de los Charrúas que poblaban las costas del Rio de la Plata, y con los guayanás de tierra adentro."—Lozano, Vol. I, p. 18.

[12] García, in Appendix I, p. 197.

[13] Alonso Ponce, 1908, p. 57.

[14] García, *loc. cit.* Ramírez, in Appendix I. p. 199. Oviedo, Lib. XXIII, cap. XII. Also later historians.

[15] Vol. III, p. 152.

elegant Indians, though ugly on account of the colors with which they make themselves look formidable, and they adorn their shameless nudity and heads only with beautiful feathers." Ramírez[16] speaks of plates and ear-plugs of gold and silver, and Cabot (*159*, p. 182) mentions "a headdress with certain plates of gold and copper, and some low grade silver," but these metals must have been obtained by trade with other regions, for none is to be had locally.

Guaraní houses were thatched. Their villages apparently were permanent, because in the *repartamiento* of Buenos Aires[17] (1582) "houses of the Guaranís" near Corpus Christi are spoken of as a landmark. Their canoes are said to have been well made, and they propelled them with long paddles (*180*, Lib. XXIII, cap. XII). A fragmentary canoe discovered in the muddy bottom of a small creek near the Canal Arias, now in the Museo de la Plata, we illustrate in Fig. 76. It has been described in detail by Marquez Miranda.[18] Of their weapons, we have only the statement of Oviedo[19] that they used bows. In this brief paragraph is contained all our historical knowledge concerning the material culture of the delta Guaraní, but further light is shed by the archeological remains we shall discuss.

We know nothing of their social organization except that the *repartamiento* of Buenos Aires[20] lists twelve caciques, each perhaps being the head of a village. From this we might deduce that there were many chiefs exercising little authority, but in time of war at least they united under a single leader, as is shown by the allied Indian attack on Buenos Aires under a Guaraní commander.[21]

In general, they are spoken of as constantly at war with all their neighbors, brave in combat, but exceedingly treacherous.

Brief as is this account of the Guaraní of the Paraná delta, enough has been said to show essential similarity to their kinsmen on the upper course of this river. The reader desirous of information concerning the latter is referred to the works of Schmidel, Barco Centenera, Del Techo, Díaz de Guzmán, Guevara, Lozano, Azara, d'Orbigny—all listed in our bibliography—or to more modern writers such as Nordenskiöld, Metraux, Ambrosetti, and Bertoni.

[16] See Appendix I, p. 199.

[17] In de Angelis, 1910, vol. III, p. 20.

[18] 1930.

[19] Ubi supra.

[20] These chiefs were named Taoabá, Aguaratin. Taypó, Yaguarey, Tiabo, Ayguay, Tatanó, Caruya, Mayrací, Pochian, Moropichan, and Purupi. —de Angeles, 1910, vol. III, p. 17. Barco Centenera names Yamandu, Teru, Añanguazuu, Maracopa, Taboba (Canto XII), Guazuyalo, Querandelo, Tanimbalo, Tabolelo, Yaguatati, Tecu, and Manon Calo (Canto XXIV).

[21] This incident is described by Schmidel and Barco Centenera.

QUERANDÍ

The Querandí Indians before the conquest wandered over the Pampas between Cabo Blanco on the Atlantic coast and the mountains of Córdoba. Just what happened to them after the conquest is not entirely clear, so that it may be well to review briefly their history. In 1536 they fought a drawn battle with the troops of Pedro de Mendoza, at which the historian Schmidel was present. In 1580 they formed part of an alliance defeated by the second founders of Buenos Aires under Juan de Garay, but their name does not appear in the *repartamiento* signed by Garay two years later, although Díaz de Guzmán states that they were then divided among the victors. In 1583, under the cacique Guren or Manuá, they attacked and slew Garay as he slept, while on his way up the Paraná to Asunción.[22] In consequence, several Querandí chiefs were brought to trial in 1585. Soon afterward, however, they combined with Mbeguá, Quiloaza, and Guaraní in an attempt to win back the region from its conquerors. In 1678 the name of this people appears again, and for the last time, in the *encomiendas* of Indians distributed among the inhabitants of Santa Fe.

Two explanations of what happened to the Querandí are current among Argentinian scholars. By some it is believed that they became totally extinct; by others it is asserted that they survived under the name of Pampas Indians. For the latter hypothesis there is strong historical support. Lozano[23] makes the direct statement that "today they survive with the name of *pampas*, equally barbarous but less numerous." Azara (*22*, II, p. 35) and d'Orbigny (*156*, II, p. 287) also identify the two names as applying to one group. Finally we have the statement of Camaño[24] that the Pampas had always been known to the people of Buenos

[22] See Hernando de Montalvo and Rodrigo Ortiz de Zárate, quoted in Outes, 1897, pp. 44–46.

[23] Vol. I, p. 431.

[24] "Lo que hai es que *Pampas*, Puelches, y *Tuelches* ó *Tuelchus*, son tres naciones distintas, de diferente lengua cada una; bien que entre los Pampas suelen andar algunos Puelches ayudandoles en sus correrias contra los Españoles, y suelen mezclarse en matrimonios, y asi algunas parcialidades cortas de Pampas han alterado su lengua, y hablan mas La Puelche. Los Puelches son de origen Chileno, y su lengua es un dialecto de la chilena. . . . Los Pampas han sido conocido siempre en Buenos Aires, y en Cordoba; comerciaban con los Españoles; les ayudaban en sus haciendas de campo asalariados. Los Pampas que estaban ó vivian en las haciendas del Pago llamado la Magdalena, son los llamados *Magdalenistas*, y los que vivian en las haciendas del Pago de Matanza se llamaban *Matanceros;* mas estos nombres jamas se dieron á los Puelches, que eran conocidas en Buenos Aires con nombre de Serranos; y mucho menos à los Tuelchus, que no eran conocidos, sino confusamente baxo el nombre de Patagones. Todo esto es constante, cierto, y notorio desde que fundaron los pueblos sobredichos; mas lo ignoraba el Padre Losano, que murio antes que se escribiesen acuratas relaciones de aquella Mision."—Camaño, MS., f. 27.

Aires and ranged as far as Córdoba, which is the exact habitat of the ancient Querandí. He adds that they merged in part with the Araucanian-speaking Puelche and acquired that tongue. Lehmann-Nitsche (*111*) has made a detailed study of eighteenth-century linguistics in the Argentine plains, but has not attempted to correlate the tribal names then prevalent with those of the sixteenth century.

Historical accounts of this tribe are more abundant than those describing their neighbors, except the Charrúa. Moreover, these data have been brought together and analyzed in a scholarly study published in 1897 by F. F. Outes, on whose work we have drawn freely. All the early sources depict the Querandí as a wild, fierce, warlike people—one of the many who once wandered without restraint on the open plains of the southern continent. Schmidel has compared them to the Gypsies, while Lozano, seeing the Pampas Indians ahorse, has likened this tribe to the Tartars.

The cultural affiliation of the Querandí has been the subject of controversy. In brief, an Araucanian origin has been proposed by Lozano (*125,* I), de Angelis (*18*), Moreno (*141*) and Burmeister (*37*); but Trelles (*230*), Ameghino (*12,* I) and Zeballos (*236,* p. 54 et seq.) argue that they were Guaraní. Finally, Lafone Quevedo (*91*) and Outes (*159,* cap. I, II, appendix I) believe that they were connected with the Guaycurú. The present writer finds himself fully agreed with Outes, whose comparative table of historical data establishes beyond argument the basic similarity of Guaycurú, Querandí, and Charrúa. At the same time it seems that the Querandí were affiliated also with the tribes to the south and to the west, but the primitive state of those tribes, before modifications due to the acquisition of the horse took place, is practically unknown to us today.

In regard to the physique of the Querandí, Oviedo (*180,* Lib. XXXIII, cap. III), on the authority of Alonso de Santa Cruz, states that they were not so tall as the Patagonians (Tehuelche),[25] but were taller than the Germans, and that they were a robust people, brown in color (*180,* Lib. XXXIII, cap. XII). Other authorities, in similar tenor, might be cited. In general, it seems that the migratory tribes of the plains, from the Chaco to the Straits of Magellan, increased in height as one went southward, and probably the Querandí fitted into this comprehensive development in stature.

Today we know not a single word of the Querandí language although, according to Del Techo (*218,* Lib. I, cap. XLIX), Father Alfonso Barcena compiled a vocabulary, grammar, and catechism in their tongue.

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[25] 175 cm., according to the figures of Moreno and Lista.

There is a tendency among modern scholars to believe that they spoke a dialect of Guaycurú, an opinion based on geographical propinquity and cultural similarity. The name Querandí, we should add, is of Guaraní origin and is derived from *quira,* meaning grease, and *ndi,* a possessive suffix. Hence it indicates "the people who have grease."

The clothing of the Querandí consisted of a small apron of cotton or skin, and a fur robe. Schmidel (*202,* p. 7) writes that they were clad like the Charrúa, who ordinarily went "quite naked, the women having only their privities covered, from the navel to the knee, with a small piece of cotton cloth." As the Querandí had no agriculture they could not have grown the necessary cotton, so they must have obtained it by trade from the north. We have no exact description of their fur robes, merely the statement of Oviedo (*180,* Lib. XXXIII, cap. XII) that they wore "mantles of various kinds," and the mention by Schmidel (*202,* p. 9) of "furrier-work made from marten or so-called otter." We do not know whether they painted or tattooed themselves, or whether they wore labrets and nose-plugs like their neighbors to the north, but it is stated that they wore headdresses of gold or silver, which they obtained by trade.

For food, the Querandí depended on game, fish, and various roots, but they had no agriculture. Guanaco, ostrich, and deer furnished their principal meat supply, and they caught fish in the rivers by means of nets. Owing to the lack of water on the plains they drank the blood of the game that they secured, and likewise ate the roots of thistles to quench their thirst. Kroebel relates that when General San Martín feasted the Pampas they drank the blood of mares, mixed with gin.[26] Musters[27] writes that the Tehuelche did not eat fish, so this diet among the Querandí points distinctly toward the north. In preparing fish for eating, they first extracted the grease, dried the flesh, and then ground it into a powder which could be kept for some time. The discovery of mortars among archeological remains (Fig. 66) and the mention of this piscine "flour" has led some erroneously to believe that the Querandí were agriculturists, but the only early writer to assert it is Barco Centenera, a most untrustworthy if picturesque authority. The Tehuelche likewise used mortars, although they practised no agriculture.

In ancient times the Querandí used a windbreak rather than a true house. Oviedo (*180,* Lib. XXXIII, cap. III) writes: "Their houses are a parapet, like half huts of the skins of deer and animals which they kill,

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[26] 1914, vol. I, p. 140.

[27] 1871, p. 201. They "even expressed great disgust at the very idea."

much painted and dressed for protection against wind and rain." This type of skin shelter was also once in use throughout Patagonia (*123*, pp. 59–62) and northern Mendoza (*195*, II, pp. 97–98), and has been employed until recently by the Ona and Haush of Tierra del Fuego. Similar forms made of poles covered with thatch are still in use among tribes of the Chaco, such as the Lengua.[28] It cannot therefore be determined if it is a northern or a southern cultural feature, and indeed this form of shelter appears sporadically among the more primitive tribes throughout both continents of the New World. Lozano (*125*, II, p. 83) writes that they had in addition houses made of reed mats—*ciertas esteras*—which also were used by the Yaro and Charrúa, as well as by northern tribes, such as the Abipones, Lengua, Toba, Mbayá, and Frentones.

The weapons of the Querandí consisted of bows and arrows, darts, slings, and bolas. We have no description of their bows, but assume they were short like those of the surrounding tribes. When they attacked the first settlement at Buenos Aires, they employed arrows made out of cane, with fire on their points, and also arrows made from a very inflammable wood with which they burned the houses and ships of the Spaniards.[29] Their darts are described as half-pikes with stone heads, and from archeological evidence they employed spear-throwers.[30] They are said to have been exceedingly expert with the bolas and to have caused heavy losses to the Spanish cavalry. In fact this weapon was the best defence that any of the American Indians had against European horsemen.

In hunting, this people depended chiefly upon their bolas to secure the larger game. Both Ramírez[31] and Oviedo (*180*, Lib. XXIII, cap. III) state that they were such swift runners that they could catch a deer—a feat we shall discuss in connection with the Charrúa. In fishing they used nets, but there is no mention of their having employed canoes.

They made war after holding a council where each chief gave his opinion and a commander-in-chief was chosen. As a first measure they secreted their women and children. In attacking they took advantage of the terrain, and we find them charging the Spaniards as the latter were involved in the difficulties of crossing a deep stream. Their assault was delivered in fixed formation, but this apparently was not maintained in battle and, as among so many Indian tribes, if their commander was

[28] Grubb, 1914a, illustrations facing p. 56. Also Palavecino, 1930.

[29] Nordenskiöld (1919, p. 52) lists the users of fire-arrows as follows: Mataco, Chorote, Abipones, Tupinamba, Chavantes, River Plate Indians, Indians of Oyapock estuary (Guayna), Cusco, and the Lesser Antilles. The Maya of Yucatan and various North American tribes may be added to this list.

[30] See Fig. 74.

[31] Appendix I, p. 201.

slain they withdrew to appoint another. Their captives were treated with kindness.

According to Del Techo (*219*, pp. 642, 653, 682) the Querandí cut off the heads of the slain and kept them as trophies. Across the Río La Plata, the Charrúa are said to have skinned the heads of the dead. In the Chaco, the Guaycurú used to keep the skulls of fallen enemies, and the Guaraní used such skulls as drinking cups, a custom found also among

FIG. 3.—Charrúa and Querandí Indians. (After Ottsen.)

the Araucanians in Chile. The Frentones kept the entire bodies of their foes and lashed them upright as a warning to those who would invade their domain.

We know nothing of Querandí home life, but can picture them crouching around their fires after the fashion of the Ona. Their domestic utensils consisted of the pottery and bone implements which we shall describe, and baskets so tightly woven that they would hold water (*180*, Lib. XXXIII, cap. III). We postpone for the moment discussion of the relationship of these artifacts.

Their social organization apparently was loosely drawn, for it is repeatedly stated by early chroniclers that they had no fixed abodes or laws. Probably they were divided into small hunting groups based on kinship, each with its own petty chief.

"They celebrate the birth of their children," writes Del Techo (*219*, p. 658), "with abundance of tears, saying when they are born they begin to die. At the funerals of their kindred, instead of tears they shed abundance of blood."

In sickness, according to Lozano (*125*, I, p. 432), they summoned a shaman who, if death took place, received the blame, and might therefore be killed in retaliation.

Their burial customs are described by Del Techo (*219*, pp. 658–659) who asserts: "They carefully keep the bones of their relations; nor is there any affront they revenge with so much war and slaughter, as for upbraiding of them that the bones of their ancestors have been lost for want of looking after. They honor their dead *Caciques* by killing their slaves, believing them to be sent after their masters to serve them." At a post-Conquest and presumably Querandí campsite on the Arroyo Sarandí, excavated by the Thea Heye–La Plata expedition, the burials were inhumations of both a primary and a secondary character. Funeral accompaniments were not found, which may be attributed to missionary influence or to the disappearance of perishable objects.

Lozano (*125*, I, p. 432) states that the Querandí cut off a finger joint as a sign of mourning. This custom existed among the Charrúa, Yaró, Minuané, Timbú, and probably other tribes of the vicinity, but is not assigned to the Querandí by contemporary writers.

Our knowledge of Querandí religion is confined to the supercilious remark of Lozano (*125*, I, p. 431) that they were "*finísimos ateistas.*"

GUAZUNAMBÍ

Lozano (*125*, I, p. 142) writes that between the upper course of the Luján river and the Río de las Conchas, "there was situated the settlement of the *guacunambis*, who amounted to six hundred families"; that is to say, about 3,000 individuals, and he adds that not even the site of their habitations was known in his day, although they had been extinct only about fifty years. This name has survived in the Arroyo Guazunambí, which flows into the Luján a short distance west of the town of El Tigre, as shown in Fig. 6. To discover the affiliations of this tribe is of importance to us, because the campsite we excavated on the Arroyo Sarandí probably lies in their territory, and indeed we first visited the location by ascending the Guazunambí (which is navigable in small boats, while the Sarandí is not), and passing across the intervening territory by wagon.

Several factors enter into a solution of this question. In the first place; the name Guazunambí itself is Guaraní, meaning "big ears," but this is of little account, as many non-Guaranitic tribes of the region are known by names of that tongue. Secondly, Azara (*22,* I, p. 179) states that the Guaraní lived not only in the delta islands, but that "they also occupied the territory of San Isidro and of Las Conchas." Thirdly, the discoveries of Oliveira César [32] on the Río de las Conchas are practically identical with the remains we unearthed on the Sarandí, indicating archeological uniformity extending from one to the other of these streams which flank the Guazunambí. Were this the only available evidence, we might be tempted to conclude that the Arroyo Sarandí campsite was inhabited by Guaraní, but the excavated specimens also have a story to tell. These include bolas, pegs for spear-throwers, and pottery showing relationship with incised wares extending well into Patagonia. At the same time, the large jars and bowls, the typical shapes, and the painted and corrugated adornment characteristic of Guaraní ceramics are totally absent. On the whole, the Sarandí finds check with discoveries from other sites which have been pronounced Querandí.

We probably then should regard the Guazunambí as a subtribe of the Querandí. The geographical location and chronological plane of what was excavated on the Sarandí both suggest that the remains represent the Guazunambí, while these finds in themselves indicate Querandí affiliation.

CHARRÚA

In the sixteenth century Charrúa Indians lived on the west bank of the Río La Plata, extending northward as far as the Río Negro and eastward over approximately half of the present Oriental Republic of Uruguay. We must take them into consideration among the delta tribes in the present work, because, after the Conquest, many of the Charrúa actually moved to the delta (Province of Entre Ríos) and finally were forced to settle in Concepción de los Charrúas on the Paraná. Secondly, the Charrúa may be regarded as typical of the migratory tribes of the R. La Plata and, since they were not exterminated until the nineteenth century, we have much more information concerning them than concerning their neighbors.

Physically the Charrúa are described by Azara (*22,* II, p. 9) as standing an inch higher than a Spaniard, with dark skin, wide nose, thick hair, small hands and feet. D'Orbigny (*156,* I, p. 85) wrote that they were not so tall as indicated by Azara, but that they were the most dark-

[32] 1895.

skinned of all the Indians. A Charrúa who was in Paris in 1831 has been studied by Pritchard (*187*, I, pp. 111–112), while a photograph of a statue made at that time has been published by Outes and Bruch.[33] In regard to the dark skin of these Indians, it seems certain that by the eighteenth century they had assimilated a large amount of negro blood, for Lozano [34] states that the land of the Charrúa was "the Geneva of these provinces, where there seek refuge not only Indians, but meztizos, negroes, and even, though it cause horror, some Spaniards who desire to live unbridled. . . ."

Only three words of the Charrúa language are known today. On the basis of these, Schuller (*206*) is of the opinion that their tongue was related to Guaycurú, a conclusion borne out by cultural data (*205*). Hervas, whose information must be given due weight because he derived his knowledge from expelled Jesuit missionaries, connects the Charrúa tongue with Bohané, Minuané, Yaró, and Güenoa.[35]

Contemporary descriptions of the Charrúa speak of them as warlike, turbulent, revengeful, treacherous, silent, swift, and little persevering.[36] They are pictured as daring, cruel in battle, but afterward humane and merciful to their captives (*156*, II, p. 89). All accounts agree that they were nomadic hunters and fishermen, without agriculture and without fixed abodes. "The reason that they give for wandering ever vagabonds," writes Father Lozano (*125*, I, p. 409), duly shocked at their impiety, "is as barbarous as their souls, for they say that they cannot bear to be forever beneath the same Heaven."

Culturally the Charrúa were practically identical with the neighboring Minuané, Yaró, Bohané, Martidané, and Chaná (*125*, I, p. 411; *156*, II, p. 83 et seq.) of whom little is known beyond this fact. Looking farther afield, connection may be seen with the Guaycurú tribes of the Gran Chaco, an affiliation recognized by the early missionary fathers.[37] D'Orbigny (*156*, II, p. 20) points out, however, that the Charrúa were completely nomadic, whereas such Chaco tribes as the Mocoví, Lengua, and

[33] 1910, fig. 71.

[34] Vol. I, p. 411. The importation of negroes, according to Báez (1926), began in 1586. In 1591 the *Consejo de Indias* granted a license for the importation of 500 negroes annually for ten years to Buenos Aires. In addition there seems to have been much contraband traffic in slaves, many of whom were sent across the mountains to the wealthier land of Peru. Lozano (vol. I, p. 144) declares that in his day the English annually brought several shiploads of negroes to Buenos Aires.

[35] "Dialectos de la lengua Güenoa son los lenguajes Yaro, Minuane, Bohane, and Charrua."—vol. I, p. 187. marginal note.

[36] Figueira, 1894. p. 19.

[37] "Necnon Charruas Iarosios ac alios populos Guaycureis simillimos" writes Del Techo (1673, lib. IV, cap 1).

Abipones, though wanderers, strayed only within fixed limits because they were agriculturists. Comparing the Charrúa with the Puelche, the same authority (*156*, II, p. 91) adds that both groups were non-agricultural nomads with similar customs, diet, government, house types, and fundamental religious concepts. They differed, he continues, in physique, in language, and in the details of their religious observances.

FIG. 4.—Charrúa Indian. (After Pernetty.)

The dress of the Charrúa in their primitive state consisted of a small apron of skin or cotton (*202*, p. 7) and a fur mantle.[38] Although not agriculturists, it seems quite probable that they did wear cotton garments, for Lozano (*125*, I, p. 410) writes that when not at war with the Guaraní tribes of the Chaco they traded with them, and d'Orbigny (*156*, II, p. 88) also says that they secured woven materials from the Guaraní. No example of the fur robes has survived, but an old engraving, reproduced in Fig. 4, shows that they were adorned with painted patterns which suggest ancient Tehuelche robes, modern Mataco robes, and designs in-

[38] Pero López, in Appendix I, p. 205.

cised on ancient pottery from the Chaco to Patagonia.[39] Azara (*22,* II, pp. 12–13) states that in his day the Charrúa men usually went naked, but put on a skin shirt and poncho in cold weather, while the women habitually wore a poncho or sleeveless cotton shirt.

For decoration, Charrúa men wore nose plugs or labrets. Pero Lopez,[40] in the sixteenth century, wrote that they bored holes in their nostrils, in which they inserted shining pieces of copper. Azara, in the early nineteenth century, does not mention nose plugs but states that the men wore a labret four or five inches long, evidently of the type found among the Guaraní of the upper Paraná. The hole for this was pierced in the lower lip a few days after birth, and the labret thereafter was worn continuously, even when asleep. According to the same authority, three vertical blue lines were tattooed on the faces of girls at the time of their first menstruation. Both men and women wore their hair long, and combed it with their fingers to remove the vermin. The women did not confine their hair, but the men made a knot on the back of their necks and inserted white feathers (*22,* II, pp. 9–10, 11).

Food of the Charrúa consisted of game and fish, and they had no agriculture. After the Conquest they lived chiefly on the wild cattle which overran the Banda Oriental.

Two distinct types of houses seem to have been in use, one in the sixteenth and one in the nineteenth century. The former, described by Pero Lopez,[41] consisted of four mats set up to form a roofless square. Similar shelters made of mats were employed by the Yaró, the Abipones, Frentones, and by the inhabitants of Tucuman,[42] as well as the Lengua, Toba, and Mbayá (*149,* pp. 23–24). This also suggests the windbreak used by the Querandí and the Ona and Haush of Tierra del Fuego, which there is reason to believe also was found throughout Patagonia before the advent of horse transportation (*123,* pp. 60–62). In later times, Charrúa houses were constructed with arched saplings covered with a single horse or cow skin (*22,* II, pp. 11–12). If the family were large, two such shelters became necessary, under which the inhabitants slept on skins.

At the time of the Conquest, the Charrúa seem to have lived more on fish than they did in later centuries when the use of the horse and the presence of huge herds of wild cattle facilitated a hunting existence.

[39] The nature, distribution, and affiliation of these patterns has been discussed by the present writer (1929).

[40] Appendix I, p. 205.

[41] Appendix I, p. 204.

[42] Del Techo, 1732, pp. 650, 653, 741. Of the Frentones he writes, "They carry about their towns at pleasure, having no houses but mats, which they set up where they think fit, like pens for sheep."

Consequently canoes and water transportation played an important part in their primitive mode of life. Pero López [43] writes of the Indians seen near Montevideo: "Their canoes were 10 to 12 fathoms in length and half a fathom in width; the wood was cedar, very beautifully worked; they rowed them with very long paddles decorated by crests and tassels of feathers on the handles; and 40 men all on foot rowed each canoe." According to an *informe* of Hernando de Montalvo, written in 1576 (*160,* p. 56), the Charrúa approached the vessels of Ortiz de Zárate in canoes. López Vaz (*231,* p. 44) describes the escape of three English captives in a canoe during the year 1583. D'Orbigny (*156,* II, p. 88), however, writing in the nineteenth century, declares that this people had no fishing, navigation, agriculture, or weaving. Cultural atrophy evidently had taken place between the sixteenth and nineteenth centuries.

The primitive weapons of the Charrúa included bows and arrows, spears with fire-hardened tips, clubs, and bolas.[44] Their arrows are described as short (*22,* II, p. 18), but they are said to have been good bowmen, and the hunting range of their arrows was up to a hundred yards (*125,* I, 407). Their bolas originally consisted of a single stone with a cord adorned at the end by a tuft of ostrich feathers.[45] After the Conquest the two- and three-ball types came into use. Acheological examples of Uruguayan bolas have been discussed by Ameghino (*11*) and Leguizamon (*105*). With the advent of horse transportation, the Charrúa, like other Indians of the southern plains and of Chile, employed in warfare (*22,* II, p. 17) great lances a dozen feet long.

A peculiar trait of the Charrúa, also found among the Querandí, was that they ran down game afoot (*125,* I, p. 407), a custom which perhaps explains the use of hunting nets mentioned by Pero López.[46] No account of just how this was done has come down to us, but other tribes in the New World, inhabiting open treeless plains, have secured their quarry by running it down. For instance, the Seri Indians of northwestern Mexico accomplish it in the following manner: A group of five or six men, having discovered, perhaps, a deer, will form a large circle around it. They do not close in on their prey, but the nearest individual, suddenly showing himself, will frighten it and cause it to run to the other side of the circle, where another pointsman will check and turn it. After thus running the animal back and forth until it is exhausted and confused, the

[43] Appendix I, p. 204.
[44] Pero López. See Appendix I, p. 205.
[45] Pero López, ubi supra.
[46] Appendix I, p. 205.

hunters close in and capture it.[47] The Huarpes of San Luis and northern Mendoza, who resembled the Querandí and Charrúa in culture if not in warlike spirit, also caught game afoot, but in a simpler and more tedious manner. "In hunting deer," writes Ovalle, (*179,* Lib. III, cap. VII) they draw near them and follow afoot at a half trot, keeping them always in sight, without letting them stop even to eat, until within a day or two they become tired and exhausted, so that they easily approach and take them."

The Charrúa, like most of the Indians of the southern plains, were fierce and indomitable warriors. After a long and arduous campaign the Spaniards under Ortiz de Zárate (*53, 25, 125*) inflicted a crushing defeat on them in the year 1573. This event, however, in no way subdued their spirits, and thereafter we find them exterminating their neighbors, the Yaró and Bohané (*22,* II, pp. 6–7), and committing constant depredations against Spanish settlements. In 1760 the Charrúa who had moved to Entre Ríos were subdued by soldiers from Santa Fe and forced to live in a mission settlement known as Concepción de los Charruas (*33,* p. 68). As recently as 1827 we find 500 of them fighting in the Argentine army against Brazil (*156,* I, p. 85), and in 1832 the last of them were treacherously slain on the banks of the Río Queguay opposite the mouth of the Luján (*1,* p. 16). In short, the conquest of the Charrúa was completed only by their extermination,[48] and they left as a heritage to the now peaceful República Oriental de Uruguay that turbulent unrest so well depicted by Hudson in *The Purple Land.*

Methods of warfare among the Charrúa were simple. As a first measure they hid their women and children in some wooded place. They then sent scouts ahead, and advanced against the enemy with the utmost precaution in order to deliver a surprise attack. The assault itself was accompanied by wild shouts, and was mercilessly pushed home. In battle they spared only the women and children, but afterward all prisoners were incorporated into the tribe, and treated with kindness (*22,* II, pp. 18–20). They are said to have skinned the heads of their fallen foes and to have kept them as perpetual trophies, and also they cut upon their bodies a tally of their victories (*125,* I, p. 408).

Of their life about camp little is known. It is said that the men would ride in and go to sleep, leaving their wives to unsaddle and groom

[47] See W. J. McGee in *17th Annual Report, Bur. of Amer. Ethn.,* pt. I.

[48] "Han sido de caracter tan insociable," wrote Araujo (1903, p. 96) in 1803, "que en 200 años no se ha podido conseguir su civilización, permitiendo mas bien acabarse, hasta reducirse el número de 200 ó 300 familias que oi existen todavía independientes, y enemigas nuestras."

the horse, gather firewood, etc. (*125*, I, p. 407). Fire they made with a hard and a soft stick (*125*, I, p. 409). In the old days they had no games, dances, or songs (*22*, II, p. 14), but as a result of Spanish contact they became card-players (*125*, I, 409). The heads of families, but not the women or children, at times got drunk on spirits obtained from the Spaniards, or on wine they made of honey (*22*, II, p. 24).

Their government was very informal, as they had no chiefs except in time of war. The heads of families, however, formed a sort of council which ran the encampment, posted sentries, etc., but obedience to their decisions was purely voluntary. Quarrels they settled by fist-fights (*22*, II, pp. 15–16).

Marriage took place on reaching the age of puberty. Ordinarily a woman married the first man who asked her. Polygyny was permitted, but was restrained by the fact that a woman with no children tended to abandon a man with several wives if she had the opportunity to become the only wife of another. Adultery, if discovered *in flagrante delictu*, led to fist-fights, but was not otherwise penalized. No bars to marriage on account of consanguinity existed, but brother and sister marriages were unknown. The children grew up wild and unruly, and showed no respect for their parents (*22*, II, pp. 21–23).

When an individual became ill, a shaman was summoned, who, as among the tribes to the south, attempted to remove the cause of sickness from the body by suction (*22*, II, p. 25).

When death took place, according to Azara (*22*, II, p. 25), the body was carried to a cemetery to the accompaniment of much wailing, and there it was interred together with the arms and utensils, while a horse was slaughtered on the grave by a friend or relative. Pero López[49] has described one of their cemeteries as consisting of a circle of upright stakes encompassing some thirty burials. Within he found much abandoned property, such as nets, skin cloaks, spears, etc. Lozano (*125*, I, p. 408) writes, however, that "they carry the bones of their deceased relatives wherever they wander, love making very light for them this stinking cargo." These seemingly contradictory statements probably indicate that each group had its own cemetery, and if death took place at a distance the body was carried with them until they reached their own place of burial.

After the burial of a relative both men and women passed a long and painful period of mourning. Azara (*22*, II, pp. 25–26) wrote that the women cut off the joint of a finger, and, with the knife or lance of the

[49] Appendix I, p. 205.

deceased, they lacerated their arms, breasts, and sides. They then retired to their huts, where they passed a period of two moons with very little food. This authority states that both a man's wives and sisters underwent this trial, and that no adult woman was to be seen who did not lack finger-joints and was not covered with scars. Pero López,[50] however, attributes this custom to the men, and he adds that he saw many old men who had sacrificed all their fingers and had only the thumbs remaining.

This brutal custom apparently extended to the neighboring tribes which we have listed as resembling the Charrúa in culture. It is ascribed to the Minuané by Azara and to the Querandí by Lozano, but none of the earlier authorities speaks of it in connection with the latter group. Finger amputation also is found sporadically throughout South, Central, and North America, but among such widely separated peoples that no obvious cultural connection is involved.

Charrúa men did not mourn the death of wife or child, but all adult males were expected to undergo a painful ritual on the death of a father. For two days they remained naked in their huts, eating only the flesh and eggs of partridge. When this period was over, a friend or relative appeared at nightfall with a quantity of short rods, which he thrust through the flesh of the mourner from wrist to shoulder. Thus arrayed the unfortunate man went naked into the woods, fearless of wild beasts, from which they believed themselves immune at this particular time. With him he carried an iron-shod stick in order to dig a deep hole, and in this pit, covered to the chest with earth, he had to pass the entire night. When daylight came he emerged from his retreat and went to a small hut, especially reserved for mourners, where presumably he removed the rods from his flesh. Two days then passed while he lay without water or food. Afterwards for ten or twelve days the children brought him partridge meat and eggs, but in small quantity, and during this time he could hold speech with no one.

MINUANÉ OR GÜENOA

Neither the name Minuané nor Güenoa [51] appears in the earliest literature, and there is no mention of them until the publication of missionary works. Most writers have assumed that the names refer to separate

[50] Appendix I, p. 205.

[51] See pp. 89–92.

tribes, but we have treated them as a single group,[52] because of a very definite statement by Lozano that the two were one.

Azara (*22*, II, pp. 30–35), who has given us the most detailed account, states that their original home was on the plains of Entre Ríos to the north and northwest of the Paraná delta, and that in 1730 they crossed to Uruguay, where they allied themselves with their Charrúa kinsmen in various wars against the colonists of Montevideo.

Azara writes that in physical type the Minuané resembled the Charrúa, but that the language of each tribe was distinct. In this he probably erred, for Hervas groups the two together and adds that "there remained in 1767 some manuscripts in the Güenoa tongue for use of the missionaries; and Señor Camaño has sent me a very brief catechism in it; and I have looked the words through carefully, and I have found none which has affinity with the idioms of Paraguay, of which I have grammars and vocabularies" (*82*, I, pp. 196–197). Outes (*170*) has republished from the rare first edition of Hervas (*81*, XXI, pp. 228 et seq.) this fragmentary catechism,[53] and has established the close relationship between Güenoa and Chaná.

The Minuané, like the Charrúa, were nomadic huntsmen of the plains. In general the culture of the two tribes was identical, though to us it seems possible that this similarity became more pronounced after the Minuané had moved to Uruguay.

The dress of the Minuané was a small apron and a fur robe. For adornment they used a lip plug. In the eighteenth century, the women at the time of their first menstruation had three vertical blue lines tattooed on their faces, but some of them still retained the ancient practice of having but a single line. A change had also taken place among the men, for they went unpainted, like the Charrúa, but formerly some tat-

[52] ". . . la [isla] Maldonado fué habitada de los indios charrúas, que discurrian vagos por todo este pais. y ahora viven retirados entre los dos rios Paraná y Uruguay, dejando la tierra desde el Uruguay hasta el mar á la nacion de los guenoas, que los españoles de Santa Fé y Buenos Aires suelen llamar, corrompido el vocablo. *Minuanes.*"—Lozano, Vol. I, p. 26.

[53] "Lo mismo digo (que no hay en estas partes quien entienda la lengua) de las preguntas del Catecismo en lengua *Gucnoa*. Saquelas de un papel antiguo, que no contiene mas de los articulos de Fé mas necesarios escritos en dos columnas; en la una en Guarani, en la otra en Guenoa. Tampocho hai aqui quien entienda, ni sepa numerales de ella; por lo qual no puedo satisfacer al deseo de Vmd. Puedo si sacarle de la equivicacion en que esta creyendo que en la lengua Guenoa la palabra *isa* significa *uno*. No es asi. La palabra que en dha lengua significa *uno* es *Yut*, como se ve en la respuesta a la tercera pregunta, donde se dice: *detit Personas,* tres Personas, *Tupa yut temamat,* y *uno solo Dios*. El *isa* ò es adverbo que aqui equivale à solamente, ò es verbo que equivale à *es*, ò es particulo de mero ornato."—Joaquin Camaño, MS., by courtesy of Prof. Charles Upson Clark.

tooed three blue lines running from cheek to cheek across the nose, while others painted their lower jaws white.

Azara has compiled a long list of features in which the Minuané resemble the Charrúa, which include lack of agriculture, rank, musical instruments, games, and dances; similar garments, household effects, weapons, method of making war, method of dividing booty, method of settling quarrels, etc. In some cases the two tribes differed in their customs.

Marriage among the Minuané was rarely polygynous, and divorce also seems to have been infrequent. Parents retained their children only as long as they were nursing. Thereafter they were entrusted to some married relative who took complete charge of their upbringing. As a result the mourning ceremony was held not for one's true but for one's foster parents.

Sickness was treated by suction in order to remove some foreign substance supposed to be lodged in the body. The medical profession was open to men and to the older women as well.

On the death of a man, his wife and daughters cut off a finger-joint. They also cut off part of their hair and allowed the remainder to cover their faces; they covered their breasts with a piece of cloth or skin, and they remained in their huts for several days. The men went through a ritual resembling that of the Charrúa, but lasting only half as long. However, they did not pierce themselves with rods, but with large fish spines (Fig. 42). They inserted these at intervals of about an inch in the back and front of their legs, and in their arms up to the elbow, but not up to the shoulder.

YARÓ

This tribe is not mentioned in the earliest literature. According to Azara (*22,* II, p. 36), they lived on the east side of the R. La Plata between the Río Negro and the Río San Salvador. Hervas (*81,* I, p. 166) groups their language with Charrúa, but Azara claims that it was distinct. They were finally exterminated by the Charrúa, to whom they were closely related in culture. Our chief sources for the Yaró are Sepp and Del Techo, whom we quote in Appendix I.

Sepp writes that physically the Yaró men were "much of the same size as Europeans, but not quite so tall." Their faces were round and flat, and of an olive color; their legs were thick and large jointed. Both sexes wore a short apron of skin, and at times fur robes. The women wore their hair loose over the forehead, with braided tresses falling down the

back, while the men apparently allowed theirs to hang free over their shoulders. For adornment, they inserted labrets of fish–bone or feathers. Ornaments of fish–bone, shell, or feathers hung from their ears, and they wore necklaces wrought of the same materials.

This tribe practised no agriculture, but subsisted on ostriches and other birds, venison, and fish; and during the colonial epoch they lived chiefly on wild cattle.

Their houses are described as huts of straw, without a roof, evidently corresponding to the roofless square of mats used by the Charrúa, Abipones, Frentones, and others. Household furniture included vessels hollowed out of wood, spits,[54] and skins for a couch. Sepp writes that one of their chiefs slept in a hammock. This statement is of interest because it marks the southern limit of the hammock. According to Nordenskiöld (*150*, map 3), the southernmost use of the hammock is among the Cainguá who live hundreds of miles to the north. Hence it seems that either the Yaró maintained trade relations over great distances or that the hammock formerly existed among intervening peoples.

Yaró weapons included bow and arrow, and bolas. They are described as carrying arrows in their hand, from which we conclude that, like the Tehuelche, they used no quivers. With the bolas they were so expert that they could hit a bird on the wing.

We know little of their social organization. Del Techo, indeed, denies that they had any "government," but Sepp describes a chieftain evidently of some authority. He was distinguished from the others by his dress, as was his wife.

The men of the tribe were forced to undergo a rigorous initiation ceremony, during which they cut themselves severely. The Ona of Tierra del Fuego had a long and complicated rite which included burning the flesh of the novices. The Charrúa are said to have scarred themselves in token of victory. It is to the north, however, that we must look for mutilations similar to the Yaró, and Del Techo[55] has written full accounts of such

[54] For the distribution of the spit see Nordenskiöld, 1919, pp. 68–70.

[55] "They [Abipones] have also their nobility and heroes, to which honour they are advanced by degrees of excessive cruelty; for he that desires to be accounted a hero, must give proof of his bravery by enduring most horrid tortures, piercing their legs, thighs, arms, tongues, and other parts of the body not fit to be nam'd, and then tearing off the skin of all those parts with a rough stone. Five of the elders exercise this butchery upon the candidate, who if he gives the least token of feeling the pain but by never so inconsiderable a motion, is not admitted into the order of noblemen. But if he carries himself resolutely in the torture, rowling himself in his blood to denote his satisfaction,

initiation practised among the Abipones, Guaycurú, and Chiquito. Here then we find a very definite connecting link between tribes of La Plata and Chaco.

The Yaró practised finger mutilation at the death of a relative, as did their neighbors, and some of them had nothing left but the palms of their hands. According to Sepp, this custom was carried out by the men, and an entire finger was taken off at a time. Del Techo does not specify the sex, but asserts that only a joint was removed at each death. It will be recalled that Pero López attributes this mutilation to the Charrúa men, but all later authorities assign it to the women among not only the Charrúa but also the Minuané and Timbú.

BOHANÉ

Azara locates this small tribe just north of the Yaró across the Río Negro, and states that they also were exterminated by the Charrúa. Hervas places their tongue in the Charrúa group.

We have now discussed two groups culturally very distinct: first, the vagrant Minuané, Bohané, Yaró, Charrúa, and Querandí, who inhabited the open plains on each side of the Río La Plata; secondly, the Guaraní, immigrants from the north, introducers of new cultural features such as agriculture and cannibalism, who lived in permanent villages on the islands in the lower part of the Paraná delta.

In addition, there is a third group of tribes, related to the plainsmen in physique and basic culture, but owing something as well to the Guaraní, for they were agriculturists who dwelt in more or less fixed abodes. They include Chaná, Mbeguá, Chaná-Mbeguá, Chaná-Timbú, Timbú, Carcarañá, Corondá, Quiloaza, and others. The relationship of these peoples—geographical, linguistic, physical, and cultural—is a perplexing problem, difficult to solve because of conflicting data.

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then the ensigns of that honour are confer'd on him. That they may be the securer of obtaining this honour, they enure themselves from their infancy to prick and flea their limbs after this manner, so that it is frequent to see boys and youths run thorns or briars through their tongues, lips, nostrils, ears or other parts; and forcing a sort of laughter to conceal all sense of pain."—Del Techo, 1732, pp. 740-41.

". . . they [the Guaycurú] go thro' cruel trials to attain to the title and dignity of soldiers; for those that aspire to this honour are to testifie their courage to the rest by enduring most hideous tortures, boring their legs, thighs, tongues and other parts of their bodies with an arrow, and if they flinch, or complain the least, amidst their sufferings, they're excluded the honour; which that they may be the surer of obtaining, the very children used to run thorns and briers into their flesh for sport and pastime."—Ibid., p. 665.

CHANÁ

In the sixteenth century there appear to have been two groups of Chaná Indians, living respectively in the vicinity of Sancti Spiritus and on the islands opposite the mouth of the Río Negro, and these maintained their separate identities during the colonial epoch. Evidence of the existence of the first group is based, to begin with, on Ramírez,[56] who lists this tribe among those living near Sancti Spiritus. Oviedo (*180,* Lib. XXIII, cap. II), in a confused passage, places a "Janaes" river about thirty leagues above the Carcarañá. According to Pero López (*117,* pp. 55-56) it took six days to go to the Chaná villages and return to the mouth of the delta. López de Velasco (*118,* p. 561) writes that seven leagues above the Carcarañá "is a lagoon or inlet called *of the Quiloaces,* which others name *river of Timbues* or of *Janaes,* which above we called Chanaes." It was these Indians, apparently, who joined Mbeguá and Guaraní in the mission founded in 1580 by Father Luis Bolaños at Baradero (*125,* I, p. 140), and two years later we find them listed in the *repartamiento* of Buenos Aires, where a dozen Chaná chiefs are named.[57] In 1678 they figure in the *encomiendas* of the Indians of Santa Fe (*159,* App. 8) and finally about 1770 it is stated that the combined native population of Baradero, Santo Domingo Soriano (Chaná), and Santa Cruz de los Quilmes (Calchaquí) amounted to 121 families or 711 individuals (*33*).

The first mention of the other Chaná enclave is by Oviedo (*180,* Lib. XXXIII, cap. XII), who writes, "Beyond, on the northern shore [of the R. La Plata] and on a level with the Great River [Paraná], is another tribe called *chanaes,* savages. . . ." According to Azara (*22,* II, p. 30) they moved just after the coming of the Spaniards to the Uruguayan shore south of the Río San Salvador. Here they found themselves exposed to attacks by the Charrúa, so they returned to their islands. About 1650 they became thoroughly alarmed by the extermination of Yaró and Bohané at the hands of the Charrúa, so they applied for protection to the authorities in Buenos Aires. This was granted them, and as a result they settled under the tutelage of Father Bernardo Guzmán (*91,* p. 132) in the mission of Santo Domingo Soriano, which was moved in 1708 to the bank of the Río Negro near where a town of the same name stands today. In this settlement they were joined before 1678 by some of the western Chaná from Baradero (*56,* p. 169). A map dated 1688 (*228,*

[56] See Appendix I, p. 197.

[57] In Outes, 1897, Appendix 3. The chiefs are Guardiya, Araquí, Canisolo, Caraqua, Yucá, Maguarí, Aguará, Derdian, Maochun, Capiguatin, Cura, Delajan.

map 32), however, shows "Chanas" living between the Uruguay and Paraná in the province of Entre Rios, which suggests that the entire tribe had not settled in the two mission stations. Lozano (*125*, I, p. 31) wrote that in the middle of the eighteenth century there was a small number under the charge of a *corregidor* from Buenos Aires. In the beginning of the nineteenth century, before this tribe became extinct, it was visited and studied by Father Dámaso Antonio Larrañaga.

The western Chaná of the upper Paraná delta have not been described in detail by the early writers, who, by their silence, imply that no great difference existed between these people and their neighbors. We have, however, a few brief notices of the eastern Chaná of the Río Negro.

The tongue of the Chaná is described by Oviedo (*180*, Lib. XXIII, cap. XII) as guttural, a statement born out by Larrañaga, who compiled a vocabulary and grammar published by Lafone Quevedo (*91*) and Torres (*225*, pp. 467–478). The former (*94*), as well as Rivet (*194*, p. 680), group this language with Charrúa, while other linguistic students such as Schuller (*205*) believe it was related to the Guaycurú language. Outes (*170*) has shown that Chaná was related to Güenoa.

The Chaná, like the neighboring Charrúa, Yaró, Bohané, and Mocoretá, had no agriculture, but they are said to have eaten algarroba beans, which grew wild in their vicinity.[58] Their chief sustenance came from hunting [59] and fishing (*22*, II, p. 30). Their weapons are reputed to have been the bow and arrow and the spear and spear-thrower (*180*, loc. cit.). In the eighteenth century they still made excellent pottery and used canoes (*22*, loc. cit.).

Azara writes that, like the Guaraní, they disinterred the bodies of their dead after the soft parts had perished, in order to paint the bones with ochre and grease, and bury them anew with their accoutrements. The children, he adds, were buried in great pottery urns, filled with ochre and earth, and covered with broad plates.

CHANÁ–MBEGUÁ

This tribe is mentioned by Pero López de Souza [60] and by Oviedo (*180*, Lib. XXIII, cap. V). The latter places them on the northern side of the delta opposite the Chaná–Timbú, who, he says, spoke the same tongue. López encountered them at the mouth of the Paraná, but exactly where we do not know. The woman and three men he saw were clad in skins.

[58] Oviedo, lib. XXXIII, cap. xii. The bean referred to is perhaps *Hymenæa courbarii*, which resembles the St. John's bread of Europe.

[59] Ibid.

[60] Appendix I, p. 209.

The woman was beautiful. She wore her hair in a braid, and had lines painted or tattooed beneath her eyes. They had caps made from the heads of jaguars, complete even to the teeth. They used small canoes, in contrast to the Charrúa and Timbú, who had large ones.

CHANÁ–TIMBÚ

Of the Chaná–Timbú we know practically nothing. Ramírez[61] lists them among the "other nations" living near Sancti Spiritus at the mouth of the Río Carcaraña, and García[62] states that they lived on the other part of the river from the "Caracaraes." These writers, however, both distinguish them from the "Timbus" or "Atambies," which gives us reason to think that, if not a distinct tribe, they were at least a subtribe of the Timbú or Chaná. In addition, Oviedo (*180,* Lib. XXIII, cap. V) writes that they occupied the south side of the delta opposite the Chaná–Mbeguá, and that both spoke the same tongue.

Oviedo (*180,* loc. cit.) also says of the Chaná–Timbú that they were of greater stature than any other tribe of the Paraná delta, and that they normally went naked, although they had many skins of deer and otter. Their diet, in addition to the flesh of these animals, consisted of fish and maize. They also grew "calabashes," which perhaps means squashes.

MBEGUÁ

The Mbeguá are a tribe who hover in the twilight of history, for what we know about them is very little. Ramírez[63] mentions them. More explicitly, Oviedo (*180,* Lib. XXIII, cap. XII) states that "upstream from these [Guaraní] is another people called Beguaes, who live on the south side of the same river; they are few in number, and when the river rises they move to the south shore. . ." Descaliers' map (*171,* p. 675) published in 1550 shows "Beguas" between the "quirandis," or Arroyo del Medio, and the Carcarañá rivers. In the *repartamiento* of Buenos Aires (*159,* App. 3) we find the "Meguay" mentioned, and the "Bagual" are listed in the *encomiendas* of Santa Fe (*159,* App. 8). Lozano writes that some of them settled in the mission at Baradero (*ca.* 1650) (*125,* III, p. 271) and that there was a "very large town of *baguales* Indians" on the Río de Areco (*125,* I, p. 184). Barco Centenera gives the name of a chief as Caytua.[63a]

[61] Appendix I, p. 197.
[62] Appendix I, p. 197.
[63] See Appendix I, p. 197.
[63a] Canto XIII.

Culturally, the Mbeguá seem to have resembled their neighbors, the Querandí, but they had acquired the art of agriculture, for Oviedo (*180,* loc. cit.) says that "they maintain themselves by fishing and they sow something, like the above-said." From Herrera (*80,* Dec. V, Lib. X, cap. XV) we learn of "Ameguaes Indians, who live by fishing, and who gave [the Spaniards] provisions consisting of a great quantity of fish and supplied them with canoes." Ramírez[64] denies that they practised agriculture, but suggests that they wore nose, ear, and lip plugs like the Timbú. Lozano (*125,* III, pp. 174 et seq.) writes that the Mbeguá sold their Spanish captives to the Chaná.

TIMBÚ

The Timbú Indians formerly dwelt on the islands of the Paraná opposite and upstream from the mouth of the Río Carcarañá, and probably also on the eastern shore of the Paraná, where to this day exist small streams known as Timbo Colorado and Timbo Blanco. They numbered, according to Diáz de Guzmán, about 8000, although Schmidel believes there were approximately 15,000. No trace of their language is known, but it is generally assumed on the basis of cultural evidence that they belonged to the southern Guaycurú stock.

Physically the Timbú seem to have been the tallest of all the tribes living near the lower Paraná and R. La Plata. Schmidel writes that the men were tall and erect, but that the women were disfigured by scratched and bloody faces.[65] Both men and women had holes bored in their noses and ears for the insertion of small stones, white, blue, or green in color, while the men also pierced the lower lip for a labret. Lozano writes that both men and women painted their bodies with clay, but that this adornment was permitted only to those who had partaken of human flesh.

Concerning the dress of the Timbú, Schmidel states that, like the Corondá, they wore a small cotton cloth from the navel to the knee, while Oviedo says that they wore garments and footgear of deer skin. Their houses, according to Oviedo, were covered with rushes and were subdivided into apartments.

Schmidel, who lived among the Timbú for some time, explicitly states that, "these people have nothing else to eat, and have all their lives through lived on nothing else but fish and meat." Oviedo, going into greater detail, writes: "They sustain themselves by fishing, of which they

[64] See Appendix I, p. 197.

[65] Corondá women also mutilated their faces. It seems possible that they thus treated themselves in order to escape unwelcome attentions from the invading troops. One recalls the incident of François I and the burgomaster's daughter.

have great abundance; and they extract from the fish a large amount of fine grease, of which the Christians make much use both for burning in candles and for dressing deer skins. . . . They have many deer, and ostriches, and sheep like the large ones of Peru,[66] jaguars, otters, and other animals which appear like rabbits, and others of other kinds. . . ." On the other hand, Ramírez, an authority of importance, declares that "they sow maize and calabash and beans, and all the other nations do not sow and their food is meat and fish." García also claims that the

FIG. 5.—"Tiembus" Indians. (After Schmidel.)

"Atambies" ate maize, while Díaz de Guzmán lists the food which the chieftain Mangoré carried to Nuño de Lara at Sancti Spiritus as "fish, meat, honey, butter [grease], and maize."

Among the customs attributed to the Timbú is the eating of earth fried in fish grease, which is said to have been a favorite food. This diet has not been noted among any of the neighboring tribes, but has a wide though sporadic distribution throughout the New World.

The charge of cannibalism against the Timbú rests primarily on Oviedo, and has been repeated by subsequent writers. Lozano, probably on the authority of an ambiguous passage in Del Techo, extends it to the

[66] Probably not the llama, but the guanaco.

neighboring Quiloaza and Colastiné, and states that no one could paint the body until he or she had eaten human flesh. Oviedo himself never visited the Paraná, but he procured his information from actual eye-witnesses of the events which he describes, so that he may be regarded as an authority of the first rank; yet we believe that more trustworthy documents of the period show that he is in error on this question. At any rate, we should make a distinction between economic and ceremonial cannibalism.

Oviedo's belief that the Timbú were cannibals is founded on the statement that after storming the fortress of Sancti Spiritus the natives refrained from eating the slain only because they disliked the salty taste of Spanish flesh.[67] His mistake arose from assuming that the Timbú, because they dwelt in the vicinity, were the attackers. Perusal of the documents arising out of various lawsuits in which Sebastian Cabot became involved after his return to Spain clearly indicates that the fortress in question was carried not by the Timbú but by the Guaraní, who are known to have been cannibals. In these documents it is many times stated that at first the Guaraní were friendly with the Spaniards. After Cabot's return from Paraguay, however, he gratuitously insulted and injured the Guaraní chieftain Yaguarí,[68] and also imprisoned three chiefs of another tribe called Alboir, Oraya, and Alcaire, after slaughtering their families.[69] Some days later, Cabot left his settlement in charge of a garrison which a Spanish court afterward pronounced inadequate, and at the same time he liberated the aggrieved native captives. Soon afterward he sent Antonio de Montoya on a mission to "our friends," the Timbú and Caracará, in order to persuade them to join in alliance with

[67] "É hallaron á los chripstianos que avian muerto los indios como es dicho, hechos tantos pedaços, que no les podian conoçer; é aunque aquella gente comen carne humana, no les avian comido ni querian aquellos indios tal carne, porque diçen que es muy salada."—Lib. XXIII, cap. iv.

[68] "A la oncena pregunta dijo que lo que della sabe es que es verdad que por la mala gobernación y culpa y providencia del dicho Sebastián Caboto se perdió mucha gente de la dicha armada y fueron ahogados y muertos de los indios, é vido este testigo que estando el dicho Sebastián junto á una casa forteleza que tenían allí fecha los cristianos, pasaba en una canoa un indio mayoral, que se decía Yaguarí, de la nación de los guarenís, é que el dicho Sebastián Caboto . . . le dío un bofetada en la cara y echó mano al puñal para él, é que queriendo el dicho indio huir dél, le atajaron y le dieron una cuchillada en el hombro, la cual le dío el patrón de la nao en que venia el dicho Sebastián Caboto, é que despues vido cómo le echaron en prisiones; lo cual todo fué cabsa que despues los dichos indios procurasen de quemar la casa. . . ."—Testimony of Francisco Hogazón, in *Acusación del Fiscal contra Sebastián Caboto*, pp. 211-12.

[69] "Item, si saben que teniendo el dicho Sebastián Caboto presos en su casa tres mayorales indios, que se llamaban Alboir y Oraya y Alcaire, habiéndoles ya muerto á sus mujeres é hijos é parientes, los soltó imprudentemente para que se juntasen, como se juntaron, con el otro indio mayoral que se llamaba Yaguarí, y destruir, como destruyeron, la dicha forteleza . . ."—Las preguntas . . . por parte de fiscal, in *Acusación del Fiscal contra Sebastián Caboto*, p. 185.

the Spaniards against the hostile Guaraní.[70] However, the enterprise seems to have failed, or at any rate it did not fructify, as within a few days the Indians took advantage of Cabot's absence with the fleet downstream and of the inadequacy of the garrison, to carry and burn the fortress. And these Indians are explicitly stated to have been Guaraní.[71]

We have followed the somewhat complicated course of events in detail because several writers, basing their argument in large part on the claim that the Timbú were cannibals, have believed the Timbú to have been of Guaraní extraction. We believe that the weight of evidence points otherwise, and that the Timbú should be grouped physically, culturally, and probably linguistically, with the Chaná–Timbú, Chaná, Charrúa, etc. At the same time, the Timbú had acquired the practice of agriculture, probably from Guaraní influence, and as a result had come to live in permanent houses at permanent village-sites.

Schmidel (*202,* p. 12) writes that the Timbú possessed more than 400 canoes, each with a crew of sixteen men. "Such a skiff," he says, "is made out of a single tree, eighty feet long and three wide, and must be rowed as the fishermen's boats in Germany, only that the oars are not bound with iron."

How a Timbú warrior appeared is pictured by Barco Centenera and by Lozano (*125,* III, p. 161). The latter describes an Indian near Santa Fe who wore "for a helmet the hide of an elk; for shield a great shell of a certain fish [turtle?], his quiver and bow on his shoulder, and in his hands a staff proportionate to the incongruous height of his body." More specifically, Oviedo (*180,* Lib. XXIII, cap. XII) states that their weapons included the spear-thrower and dart, as well as the bow and arrow.

The use of the spear-thrower on the lower Paraná is ascribed by Oviedo to both the Timbú and Chaná. A result of our excavations on the Arroyo Sarandí was the discovery of two bone pegs for such an implement (Fig. 74); hence it appears to have been employed by the Querandí, which marks the southeastern limit of its distribution in South America. It

[70] "Item, si saben quel dicho Capitán General [Caboto] mandó al contador Antonio de Montoya con un bergantín é cierta gente á llamar á las naciones de los tambúes é caracaraes, que eran nuestros amigos, para ir contra los dichos indios guarenís, por el daño que habían hecho. . . . "—Gregorio Caro, in Medina, 1908, vol. II, p. 263.

[71] "Item, si saben que el dicho Capitán General siguió todavía su camino por buscar los dichos indios contra quien iba, sabiendo que quedaba atrás, haciendo poco caso como fué avisado del aviso que le habían dado, ni de avisarme á mí, de manera que viendo el dicho capitan absente, los dichos indios de la nación de los guarenís vinieron con gran moltitud de gente una mañana antes del día por el río é por la tierra é pusieron fuego á la dicha casa que tenían por forteleza, donde yo estaba. . . . "—Ibid, p. 264.

Lorenzo de Castro, gentil-hombre desta armada "oyó decir que fué (el dicho Capitán General) avisado de una nación de indios nuestros amigos cómo los guarenís le iba á quemar la casa. . . . "—Ibid., p. 271.

is found also among various tribes of the Chaco and Amazon valleys, while it was known to practically all the peoples of the Pacific watershed in North, Central, and South America as far south as northern Chile.

Nordenskiöld (*152*) has published an interesting discussion of Timbú arrows, in which he quotes Oviedo's remark that the arrows "were small and plumed with three feathers and well polished." In connection with this he points out that Cainguán arrows illustrated by Ambrosetti (*6*) also have three plumes and that this form recurs in North America, but not in the intervening region.

Short stiff bows and short heavy arrows seem to have been characteristic of all the plainsmen in southern South America to the Straits of Magellan and also of the Araucanians in Chile. The reason for this choice may have been scarcity of wood, but it is more probable that the Indians realized that a short and heavy arrow would be less deflected by the furious winds that often sweep the plains. In Tierra del Fuego, Ona bows are not of this form, and their distributional pattern may indicate that they represent an older type, for the same peculiar cross-section appears archeologically far to the north,[72] and a comparable technique in discharging the weapon exists among such distant tribes as the Ashluslay (*148*, tafel 12) and the Bororo (*217*, abb. 138).

Cutting off the joint of a finger on the death of a relative was customary among the Timbú women and, after the fingertips had gone, they cut off the outer joints of the toes. Ramírez declares that there were women among them without a single outer phalanx on hand or foot, and that they said they did this on account of the great grief they experienced upon someone's death. Lozano further states that this tribe adorned the graves with ostrich plumes and planted upon the spot an ombú[73] (*Pircunia dioica*) tree to which the relatives returned to bewail the defunct.

CARCARAÑÁ

This tribe, of whose name many variants can be found, presumably lived on the banks of the Carcarañá river. According to Del Techo (*218*, *219*), they numbered about 8000. All the early writers link them with the Timbú, who dwelt in the delta country across the Paraná, and

[72] *E. g.*, in the Atacameño culture of northern Chile (Mus. Amer. Ind., Heye Fdn., 9/7063).

[73] This is practically the only tree of the Pampas. It grows gnarled and knotted so that the roots, extending far above ground, afford shelter from the weather. An Argentine proverb—which I cannot quote in exact form—is to the effect that the house of the gaucho is the ombú.

it is evident that these two tribes were not only on friendly terms but were practically identical in culture.

CORONDÁ, QUILOAZÁ, COLASTINÉ

These three tribes lived on the Paraná islands above the Timbú. The fullest account is by Schmidel (*202*), who describes them as resembling the Timbú in culture, physique, and language. Lozano does not depict them individually, but by listing them with the Timbú he implies that no important differences existed.

SUMMARY

Study of historical sources indicates that the Indians dwelling on the shores of the Río La Plata and the lower Paraná consisted primarily of plainsmen related to the Guaycurú. Into their midst had come an invading band of Guaraní, and under their influence the culture of some of their neighbors had been modified. The interplay of cultural features we summarize in the accompanying table, which combines both historical and archeological data. It should be noted that the blank spaces indicate absence of information rather than absence of a cultural trait.

TABLE II

	Querandí	Charrúa	Minuanó	Yaró	Chaná	Chaná-Mbeguá	Chaná-Timbú	Mbeguá	Timbú	Guaraní
Fur robe	+	+	+	+	.....	+	.....	.....	+	.....
Apron	+	+	+	+	.....	.....	.....	.....	+	.....
Nose-plug	.....	+	.....	.....	+	.....	+	+	+	.....
Lip-plug	.....	+	.....	+	+	.....	+	+	+	.....
Ear-plug	+	.....	.....	+	+	.....	+	+	+	+
Tattooing	.....	+	+	.....	.....	?	.....	.....	.....	.....
Thatched house	.....	.....	.....	.....	.....	.....	.....	.....	+	+
Skin windbreak	+	+	+	.....	.....	.....	.....	.....	.....	.....
Mat windbreak	+	+	.....	+	.....	.....	.....	.....	.....	.....
Canoe	no	+	.....	.....	+	+	.....	+	+	+
Spear-thrower	+	.....	.....	.....	+	.....	.....	.....	+	.....
Bolas	+	+	+	+	.....	+	.....	.....	.....	+
Bow	+	+	+	+	+	+	.....	.....	+	+
Finger mutilation	+	+	+	+	.....	.....	.....	.....	+	.....
Head trophy	+	+	+	+	.....	.....	.....	.....	.....	.....
Agriculture	no	no	no	no	no?	.....	+	+	+	+

Cultural Traits of Tribes Inhabiting the Río La Plata Littoral and Paraná Delta.

ARCHEOLOGICAL INVESTIGATIONS

I.—Arroyo Malo

NATURE OF THE SITE

The Thea Heye–La Plata expedition began fieldwork with the excavation of a refuse–heap containing burials, situated on the west bank of a small stream formerly called the Guayracá,[74] but now commonly known as Arroyo Malo. To reach it, one proceeds from Buenos Aires to Tigre by train, thence by launch up the Río Luján and Canal Arias (Fig. 6) as far as the property known as La Sirena or Finca Novelino. From the dock one can reach the ancient campsite by a short walk. We reproduce a sketch map of the vicinity in Fig. 7.

Today the stream fronting the archeological remains is what is called *tapado;* that is to say, the surface of the water supports a mat of reeds, beneath which flows the current. So solid is this vegetal bridge that a man may cross dry-shod, though it will bend beneath his weight as would thin ice. Formerly the arroyo must have been open and navigable. Streams like Arroyo Malo are not uncommon in the delta district, and we read that in some places the vegetal layer actually served as a temporary burial ground.[75]

Downstream the arroyo has been cleared and deepened in recent years. Numerous drainage ditches discharge into it, by one of which it was possible to reach the scene of our labors in small boats during times of high water, and indeed the specimens secured could not otherwise have been removed without the greatest difficulty.

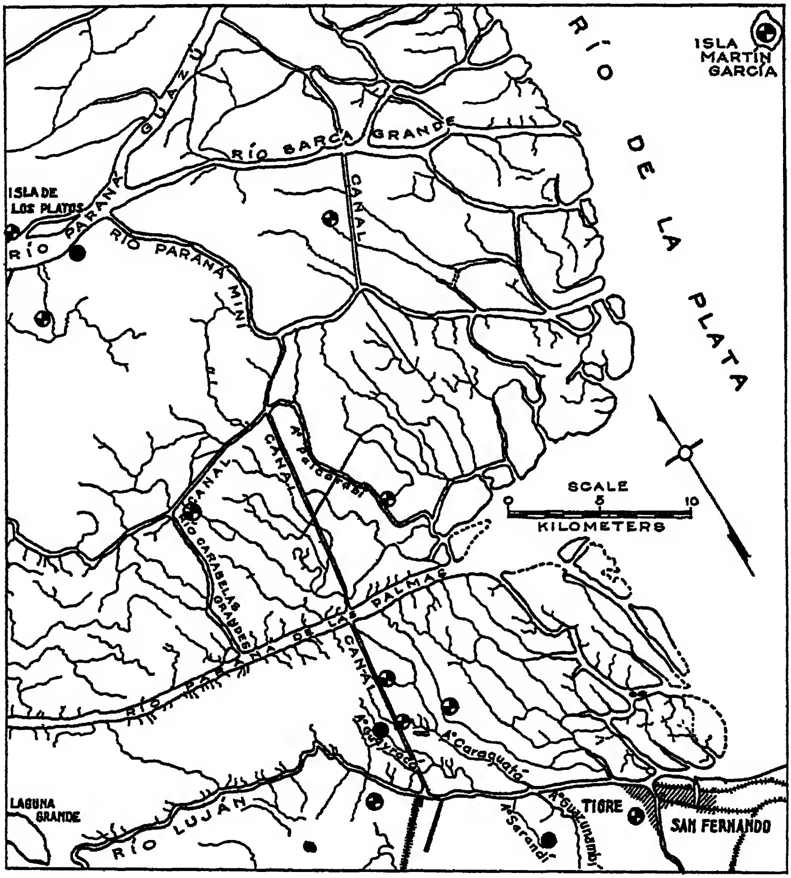
The campsite and burial-ground lie between the arroyo and a swamp (Pl. III). Most of it stands a foot or two above the normal level of the water, but several times during the course of our investigations it became completely inundated, and it must be deeply submerged by any really severe flood. Hence aboriginal houses may have been built on stilts, as is the almost universal practice among the present inhabitants of the delta.

The soil consists of a surface cap, eight to twelve inches in depth, darkened by the decay of vegetal matter, which covers a stratum of clay, varying in color from gray to yellow. The depth of this layer was not deter-

[74] This name has been wrongly applied on several recent maps to an adjacent water-course.

[75] "Los Caracaras enterraban sus difuntos en aquellos embalsados, pero muy someramente, porque así reconocen mejor cuando está la carne podrida y entônces sacan los huesos, los lavan y se los llevan consigo."—Lozano, vol. I. p. 49.

mined, as it extends far below the water-table, and no archeological remains occurred in it. Both strata were so soft when dug that a pick proved unnecessary; once a vertical face had been established, this could



| = Sites excavated ⊕ = Archeological Sites

FIG. 6.—Archeological map of the lower Paraná delta.

be pared in thin strips with a sharp flat-bladed shovel. Trowel and knife also proved of service for clearing burials, but brushes were of little use owing to the dampness and viscosity of the soil.

A peculiarity of the soil is that concretions form around any foreign substance introduced into it. This was particularly noticeable in the

case of roots and of pottery, and it added greatly to the task of excavation because potsherds were often cemented together by a material much harder and stronger than the sherds themselves. Fragments of these concretions had been used for tempering pottery both at this site and at Arroyo Sarandí.

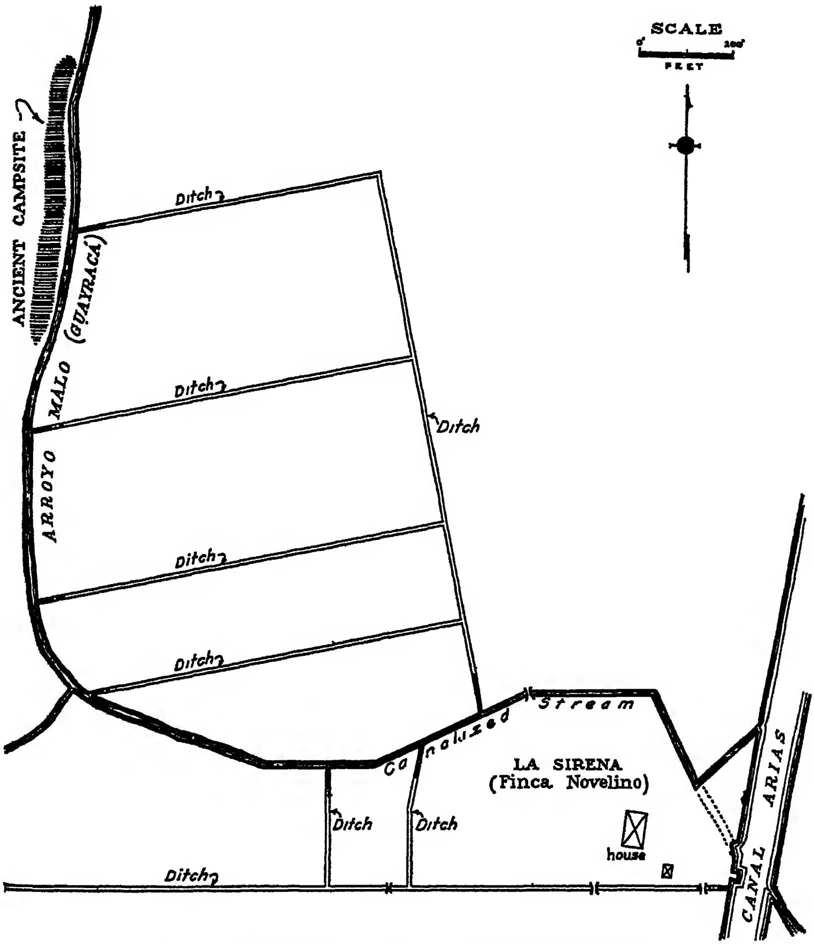


FIG. 7.—Sketch map, locating Arroyo Malo campsite.

Owing to its nature and humidity, the soil clung tenaciously to everything, especially to the soft and porous pottery, which often could not be lifted without breakage until at least partially dried. The adhering mud made fitting and matching of sherds a laborious task, while the ever-

present menace of high water urged the immediate packing and removal of what we secured.

At the time of our excavations, most of the land had just been planted with poplar trees. On the southern half of the site these were spaced two meters apart, while at the north, on another property, there was a distance of a meter and a half between trees. Owing to a boundary dispute an uncultivated strip existed. As seen on the map in Pl. III, we dug a series of narrow trenches between the rows of poplars, but by permission of the proprietors we removed the trees when any discovery indicated a reason for so doing. Fig. 8 shows the central section of the site, looking to the northwest.

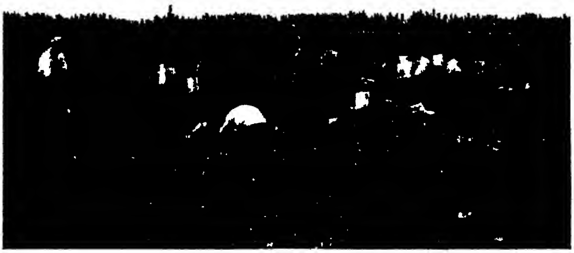


FIG. 8.—General view of Arroyo Malo excavations.

Archeological remains lay, for the greater part, between the two layers of soil we have described, though scattered fragments were found in the upper layer. At times, when the water-table permitted, we tested the lower stratum, but invariably found it sterile. Our finds consisted of camp refuse and burials. Because the hoofs of horses and cattle had penetrated deeply into the soft soil, everything breakable had been badly shattered, while the dampness had caused the decay and complete disappearance of all perishable objects except a few badly rotted human and animal bones.

Arroyo Malo clearly was the site of a Guaraní village. This was indicated not only by its location in traditional territory of this people, but by the nature of the artifacts themselves, which exhibit relationship with known handiwork of other Guaraní Indians, both ancient and modern. Furthermore, the remains were roughly dated as sixteenth or seventeenth century by the discovery of glass beads and potsherds of Spanish origin.

Two types of burial were found. The most spectacular was secondary burial in large urns capped by broad inverted bowls. As shown in Fig. 9, several large jars were grouped beside the burial urn, and these contained traces of food-offerings, and red paint. It appears that the flesh had been removed before interment because the jars which contained the

a

b

FIG. 9.—Group of burial urns. Arroyo Malo. *a*, restored; *b*, as discovered.

bones were too small to hold the entire body (Fig. 10). In placing these burials in the ground, the Indians dug a hole just deep enough to cover the inverted bowl with an inch or two of earth. As a result the bases of burial jars sometimes projected into the underlying yellow clay and were the most deeply buried remains encountered. Another result was that the bottom of these vessels usually was below the fluctuating water-table and could be recovered only by strenuous bailing. An idea of the problem presented may be gleaned from Fig. 1, which shows a bowl capping a large jar, the latter being entirely immersed in muddy water.

URN–BURIAL

Urn–burial is exceedingly common in South America. Nordenskiöld (*150*, pp. 184–195, and map 16) has made a thorough study of the distribution in that continent; he concludes that it is not necessarily characteristic of the Guaraní and that it probably originated west of the Andes. Urn–burial also is known in Panamá, the five republics of Central America, British Honduras, Mexico, and the United States (California, Tennessee, Georgia, Alabama, and Florida).[76] In Peru and Guatemala[77] this custom has an antiquity of many centuries. Looking

FIG. 10.—Burial urn. Arroyo Malo.

at the distribution as a whole, it seems probable that urn–burial is primarily a South American feature, which entered Middle America with other cultural elements (such as negative painting) before the rise of the Maya civilization.[78] Its presence in the southeastern United States

[76] Moore, 1910. Linné, 1929, pp. 213–216. Lothrop, 1926, pp. 96–97, 254–256; 1927, pp. 23-24; also manuscript notes.

[77] Mr. and Mrs. O. G. Ricketson, during the field season of 1929 at Uaxactun (Department of El Peten, Guatemala), uncovered an infant urn-burial which apparently dates from the early part of the Maya Old Empire period. This discovery is of particular interest to students of the Paraná because in addition to the infant's bones, the urn contained a finger phalanx, which the mother had evidently sacrificed. This custom is described among the Maya of Yucatan by de Landa.

[78] In a paper read at the Andover meeting of the American Anthropological Association (December, 1927), the writer pointed out that pottery traits characteristic of South America had reached Middle America before the development of the higher cultures, typical art and conventional symbolism of the latter region. This was demonstrated by an analysis of stratified remains from Guatemala, Honduras, and Salvador. In other words, South America contributed to Middle American cultures such as the Chorotegan and Mayan, and these in turn, after developing in part under these foreign stimuli, appear to have influenced the growth of later cultures in the southern continent.

is but one of several well-known yet puzzling features which link that area archeologically with Middle America.

More specifically, urn-burial is constantly associated with the culture of the Guaraní, and Lozano [79] writes of this people that they practised it because they believed that the soul, although a separate entity, accompanied the body, and they did not wish the earth to press upon it. We have already cited historical evidence that the Chaná at times used urn-burial, which they must have acquired from the Guaraní, for their linguistic and basic cultural affinity with the Charrúa and Guaycurú is fully established.

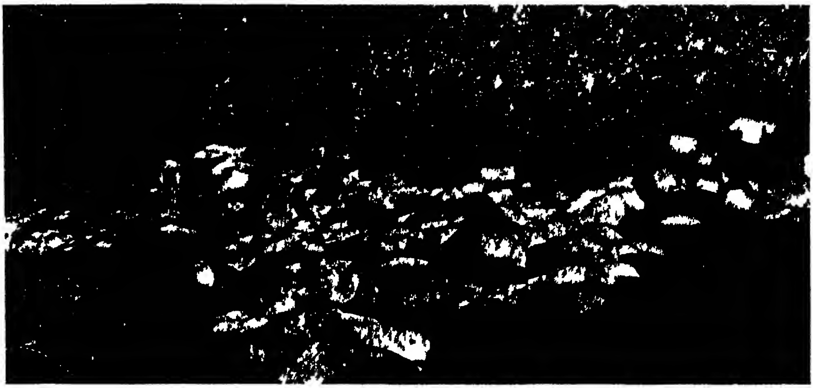


FIG. 11.—Sherd-burial. Arroyo Malo.

"SHERD-BURIAL"

The second kind of burial on the Arroyo Malo may be described as "sherd-burials," for they appear to have been inhumations accompanied by several large fragments of pottery and such funeral offerings as food, red paint, fire-dogs, stone chips and nuclei, hammers, celts, and bolas or polishing stones. Such gifts to the departed served to distinguish these burials from the general run of sherds encountered during the course of excavation, for the human remains usually had completely disappeared. This was to be expected, owing to the extreme dampness of the soil. Only four fragments of animal bone were encountered in the entire area ex-

[79] "Porque juzgaban que el cadáver acompañaba su alma, aunque, separada, le daban sepultura en una grande tinaja, tapando con un plato la boca, para que en aquella concavidad. estuviese mas acomodada el alma: bien que dichas tinajas las enterraban hasta el cuello, y algunas les ponian dentro los instrumentos de su trabajo, para que pudiesen en la otra vida hacer sus sementeras, y no se muriesen de hambre."—Lozano, vol. I, pp. 396-97.

TABLE III

Objects	Urn-Burials (A)					Sherd-Burials (B)													Total		Typical of:
																			A	B	
Jars..........	3	4	2	2	1	....	....	....	....	....	....	....	....	....	....	....	....	....	12	....	A
Bowls..........	1	1	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	4	...	A
Large sherds..........	....	....	....	....	....	?	4	3	3	3	2	8	2	3	2+	7	6	4	....	47+	B
Human bone..........	+	+	+	....	....	+	+	....	....	....	....	....	....	....	....	....	....	....	3	2	A
Paint..........	+	+ +	+	+ +	+	...	+	...	+	+	....	....	....	....	....	....	....	....	7	3	A
Food..........	+	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	A
Animal bone..........	....	....	....	....	....	1	....	....	2	....	....	....	1	....	1	....	....	....	....	5	B
Chips, nuclei..........	....	....	....	1	....	....	2	....	1	2	2	19	+	....	....	1	....	1	1	28+	B
Hammers..........	....	1	....	1	....	....	....	....	1	1	....	....	2	....	1	....	....	....	2	5	B
Polishers..........	....	....	....	....	....	1	....	....	....	....	1	3	....	....	2	3	1	....	....	11	B
Fire-dogs..........	....	....	....	....	....	2	....	....	....	....	....	4	....	....	2	....	....	....	....	8	B

Analysis of Funeral Furnishings. Arroyo Malo.

cavated, but in two instances human bones were definitely associated with sherd–burials. The first case was a badly rotted skeleton which lay on its right side with the head pointed south and the face turned to the east. With the human remains were a small smoothing stone and a bit of animal bone. This discovery was made at the very beginning of our excavations, and it seems probable that the workmen may have dug through large fragments of pottery which they would not have disturbed after they had learned their work fully.[80] In another instance, some human teeth and fragments of a lower jaw were found associated with four incomplete vessels, two pieces of fire–dogs, and two unworked stones.

Sherds representing as many as eight vessels were found intermingled in a single burial of this type, and in most cases pressure from above had flattened them, so that when cleared they presented the appearance seen in Fig. 11.

While the excavations were actually in progress we assumed that there was only one kind of interment and that what we here call sherd–burials were in fact urn–burial groups broken and scattered by plowing. This, however, was not the case, for an analysis of the funeral furnishings associated with eighteen graves, as may be seen in Table III, clearly indicates that dissimilar kinds of objects were deposited with the dead in each type of burial. The chief difference between the two is that with

Table IV

Frequency of Types

	Urn–Burial			Sherd–Burial		
Wares	Jars	Bowls	Total	Jars	Bowls	Total
Polychrome, Red	9	2	11	7	28	35
Corrugated, Incised ...	4	2	6	13	7	20
Total................	13	4	17	20	35	55

Percentage of Types

Polychrome, Red	52.9	11.8	*64.7*	12.7	30.9	*63.6*
Corrugated, Incised	23.5	11.8	*35.3*	23.6	12.7	*36.4*
Total................	76.4	23.6	100.0	36.4	63.6	100.0

Analysis of Pottery Associated with Burials. Arroyo Malo.

[80] This statement is in no way intended as a criticism of the men employed, for I have never had a more capable and enthusiastic group, who rapidly acquired a remarkable grasp of what was required and how to do it.

the sherd–burials a considerable number of stone objects were uncovered, while only three such finds occurred with urn–burials.

We have but few data bearing on the relative age of the two types of burial, but believe that they were approximately contemporaneous. In one instance an urn–burial appeared to have been made in the middle of, and therefore presumably after, a sherd–burial, but we hesitate to stress this, owing to the muddy condition of the site. In Table IV we have analyzed the pottery types found with each kind of burial, which shows, as one would expect, that more large jars are associated with the urn-burials. However, the proportion of slipped and painted wares as against corrugated or incised wares (Table IV) remains practically constant, for there is a difference of little over one per cent. in the "total" column. As will appear presently, the ceramic remains are more diversified than is indicated by our table, but we have had to group red ware and polychrome ware together because the paint on the latter had usually disappeared. The two wares are technically parallel in that both have a covering slip.

POTTERY

The ceramic remains found on the Arroyo Malo consist of the following:

1.—Corrugated ware,
2.—Nail–incised ware,
3.—Red ware,
4.—Polychrome ware.

All of these were made from the same kind of clay, which normally is yellow-brown in color, but sometimes has a red or gray tinge. Tempering is of small pebbles or fragmentary concretions such as we have described, and in either case it is present only in small quantities. Firing rarely was done thoroughly, so that sherds often vary in color from wall to wall. In this respect the corrugated and incised vessels usually are superior to the red and the polychrome wares, but we believe that this is due to the use of the former for cooking rather than to any consciously different method of manufacture. The corrugated and incised wares have no slip, but the others have a thick slip, colored red or light gray.

Corrugated Ware

Corrugated vessels are almost always large, and they take the form of shallow bowls or open-mouth jars, as shown in Pls. IV and V, *b*. The jars—characterized by a widely open mouth, outcurved rim, and a pointed

base slightly incurved on the sides—are typical of Guaraní culture over a wide area for many centuries (Figs. 13 and 21). In the Museum of the American Indian collections there are ancient corrugated vessels, found in the State of Santa Catherina in Brazil, which are practically identical with specimens from the Paraná delta. In fact, such Guaraní tribes as the Chiriguano in Bolivia, continue to manufacture similar jars to this day (Fig. 13, *a*).

The form and variety of the markings we illustrate in Pl. V. It will be observed that the vessels were built up with very large coils which were rhythmically pressed out flat. On the outside the marks thus produced were allowed to remain, but the inner wall was smoothed down and burnished. Fabrication was evidently carried out with considerable speed, for the coils did not adhere to each other with firmness, as is shown by the tendency to break along the lines of juncture. In short, the potters had ability to construct and to fire unusually large vessels, but otherwise their workmanship cannot be regarded as first class.

Corrugated pottery comes in quantity from two parts of the New World. In North America it is typical of southwestern United States, where stratigraphical studies have proved it to be an ancient technique. According to the classification and synoptic exhibit arranged by Mr. S. J. Guernsey in the Peabody Museum, Harvard University, pottery retaining the original coils placed in bands around the neck of the vessel, appears in the Pueblo I period, and in Pueblo II these bands are adorned by corrugations. In Pueblo III, the corrugations completely cover the outer wall of the vessel, and this type has continued to be manufactured until recently. Nordenskiöld, (*149*, pp. 217–218, Fig. 66, and map 40) who has discussed the distribution, south of the equator, of pottery ornamented with finger-prints, notes its occurrence as follows:

1.—Tarupayu, near the upper Río Pilcomayo.
2.—Incahuasi, between the Parapiti and Río Grande in southern Bolivia.
3.—Sara, near Santa Cruz de la Sierra.
4.—The lower Paraná.
5.—San Blas peninsula.
6.—Laguna, Santa Catherina, Brazil.
7.—Río Grande do Sul, Brazil.
8—The Lengua territory.
9.—The upper Paraná.
10.—Conceiçao mission in Brazil.
11.—Chané Indians.
12.—Chiriguano Indians.
13.—Mataco Indians.

To this we may add the discoveries by Outes (*172*, *175*) on Martín García island, and of Ambrosetti (*5*, *6*) in several sites near the Brazilian frontier. In the Museum of the American Indian, Heye Foundation,

there are several corrugated jars found by excavation in the Brazilian state of Matto Grosso, while in the Peabody Museum, Harvard University, there are similar vessels made by the Piro Indians on the Purus river in Peru. These additions do not alter the general scheme of distribution brought out by Nordenskiold, who concludes that this form of ornamentation in South America originated among the Guaraní and was disseminated by that people.

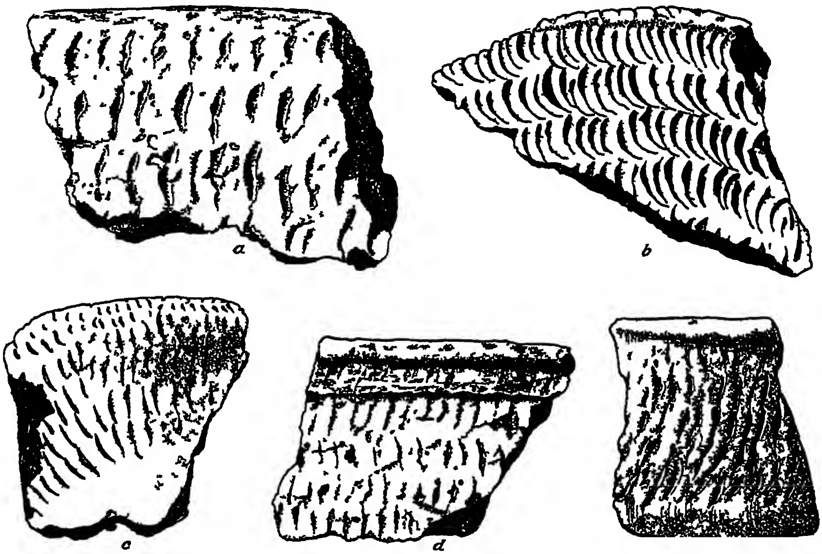


FIG 12—Nail-marked sherds Arroyo Malo. Length of *b*, 3¼ in (14/7111.)

Corrugated pottery also has been found in the upper Magdalena valley (*185*, II, abb. 86–101) and the isthmian region (*114*, Fig. 9) of Colombia. In both instances the neck coils have been indented with fingermarks in a fashion recalling the first appearance of this technique in the Pueblo area of our Southwest.

Nail-incised Ware

This group superficially resembles corrugated pottery, as it has no slip and exhibits a roughened surface, but the method of manufacture was different. In the case of corrugated ware we have seen that marks of fabrication have been allowed to remain on the outer wall of the vessel. Nail-marked pottery, however, has had both the inner and the outer wall smoothed, after which the outer walls have been roughened by in-

cisions made with the finger or thumb nail. We doubt that the makers understood the principle involved, but it is certainly true that vessels with roughened outer walls will absorb heat from a fire more rapidly and therefore are superior for cooking to smooth-walled containers. At the same time the roughness makes them less slippery, and easier to handle. Both corrugations and nail-markings, therefore, are distinctly utilitarian features.

Nail-marked vessels, illustrated in Pl. VII, as a class are small, although a few examples are of large size, such as Pl. VI, *a*. In shape, usually they are subglobular bowls or jars with slightly thickened rims. Variations in the decoration are shown in Fig. 12. It will be noted that

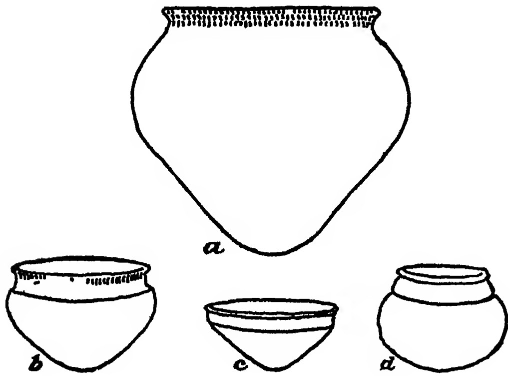


FIG. 13—*a*, modern Chiriquano nail-marked jar, *b–d*, Isla Martín García pottery (After Outes, 1909, 1918.)

there are no formal patterns, but that the indentations usually are made in closely spaced and regular lines, which completely encircle the vessel. In a number of cases the smooth interior wall had received a coat of red paint, and sometimes the incised outer wall also was colored.

Decoration of this type was practised by other Guaraní tribes. Ambrosetti unearthed examples on the Alto Paraná near the Brazilian frontier, some of which we reproduce in Fig. 21, and Outes has published specimens made in recent years by the Chiriguno Indians of Bolivia (Fig. 13). Nail-markings arranged to form patterns are characteristic of pottery we dug up on the Paraná Guazú (Pl. XIX), and are found to the south as far as Patagonia (Pl. XXVII, no. 11). We cannot say whether this technique spread from the plains tribes to the Guaraní or *vice versa.*

Red Ware

Red ware vessels from Arroyo Malo, although constructed from the same clay as the wares already considered, are technically distinct owing to the presence of a covering slip, which varies in colour from dull buff to

gray. This slip did not adhere firmly to the walls. Hence in many instances it has peeled off, carrying with it the red paint which adorned the exterior.

Red ware exhibits more elaboration in shapes than corrugated and nail-incised pottery, and also there is a great range in size. In general, large jars and bowls were associated with urn burial, while fragments of smaller vessels were found only with the sherd burials. The discovery of red ware

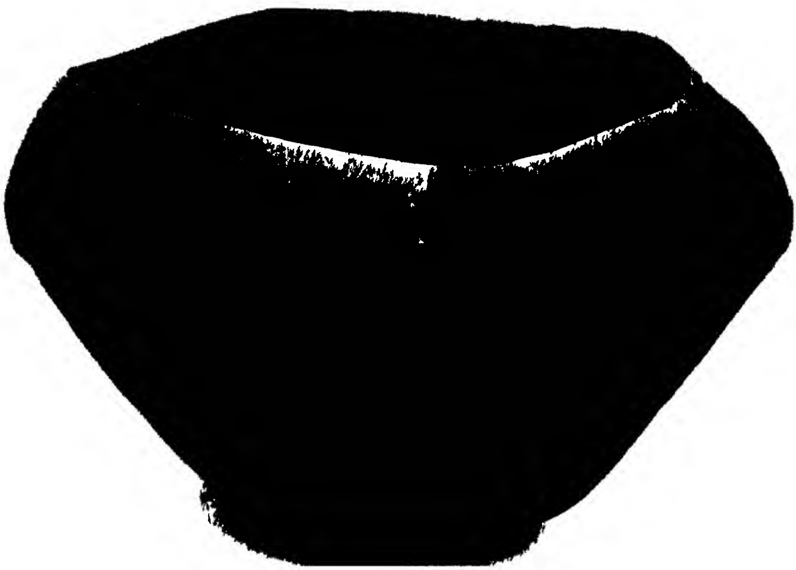


FIG. 14.—Red-ware burial urn. Arroyo Malo. Diam., 30 in. (14/7100.)

burial urns capped by corrugated bowls shows that the two were contemporaneous.

Burial urns were of the type seen in Fig. 14. They are wider than they are tall, have a sharply projecting cornice encircling the body of the vessel at the shoulder, while the orifice is comparatively small. It seems probable that during the life-time of the owner these vessels were employed for storage. The example illustrated has been cut down around the mouth. It is possible that this was done to facilitate the introduction of the bones of the deceased. We have seen a number of burial urns from Nicaragua treated in the same fashion, probably for the same purpose (*121*, cxx, cxxi). At the same time, we have seen that when present-day

Indians break the rim of a vessel often they do not attempt repairs—e. g., by crack lacing—but grind down the entire neck to form a new rim.

A second red ware group comprises wide bowls, shown in Pl. VIII, which served as covers for the burial urns. It will be noted that they have the shoulder ridge characteristic of the large jars, so that the two forms

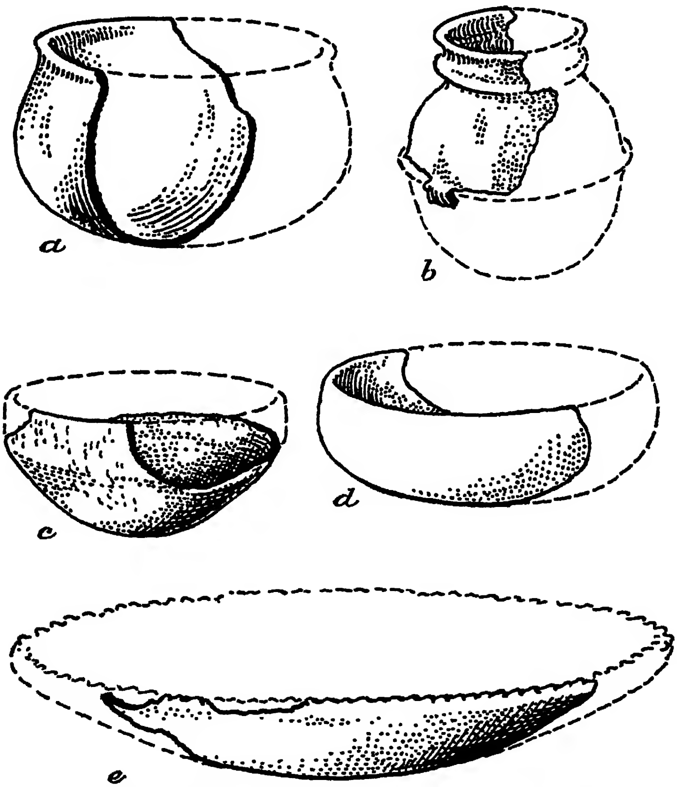


FIG. 15.—Arroyo Malo red ware. Restored diams., 4, 2⅝, 2⅞, 6, 15 in. (14/7133, 7138, 7137, 7134, 7139.)

merge into each other. Finally, there are various smaller bowls and plates (Figs. 15 and 16), which were associated in the ground with sherd-burials. This group exhibits greater variety in form than the others we have considered, and there are examples of elaboration in the treatment of rims and the use of small strap handles (Fig. 15, *b*, *d*).

Various unusual red ware forms are grouped in Pl. IX. Of these, *a* is adorned with concentric circles modeled in low relief, while *b* is covered with spikes—this apparently being the southern limit of widely

distributed pottery characteristics. Spouted handles (*d*) of the type found at Arroyo Sarandí (Fig. 55, *e, f.*) are much longer than the Querandí examples. A fragment of a double vessel with a restoration of it is shown in *e*. This type occurs sporadically both in North and in South America, for it is a shape which could be easily and repeatedly invented. According to Nordenskiold (*150,* Fig. 44, no. 26) the Chiriguano to-

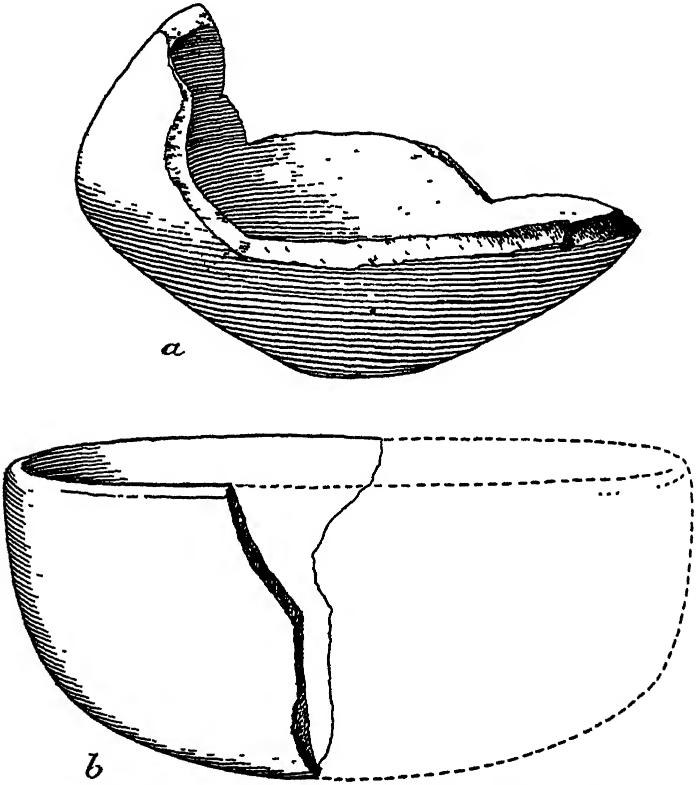


FIG. 16.—Fragmentary red ware vessels Arroyo Malo. Diams., 7, 4½ in. (14/7131, 7136.)

day use similar bowls as salt dishes. In *f* we have an effigy vessel with the face treated in a fashion typical of Arawak culture to the north and also suggesting tall jars from the Chaco and Diaguita regions. All these pieces must be regarded as freaks, but several examples of miniature pots such as *c* were obtained.

A freak piece of coiled ware appears in Fig. 17. These fragments preserve on one side the coils by which they were built up, but without

corrugations, and the whole has been covered with a gray slip, on which were traces of red paint. We have excavated a similar vessel at the Zuñi ruin of Ketchipauan in New Mexico, which is now in the University Museum at Cambridge, England.

Polychrome Ware

Polychrome pottery was apparently fairly abundant at Arroyo Malo, but of all the pieces we recovered only two still retained decipherable

FIG. 17.—Fragments of plate Arroyo Malo Length of upper sherd, 7¾ in. (14/7122.)

designs. One of these is the burial jar illustrated in Pl. X, *b*, and Fig. 10. Both in shape and decoration this vessel has affiliations with pottery found far to the north. In Fig. 18 we show a series of rim sections from the same site which exemplify the curious construction of the necks. These are similar to remains from other Guaraní sites in the vicinity, such as Martín García island.[81] They are repeated far to the north on the Brazilian frontier among specimens excavated by Ambrosetti, reproduced in Fig. 19, and they are suggested by modern pottery not only

[81] See Outes, 1918a. Figs. 7, 11 12

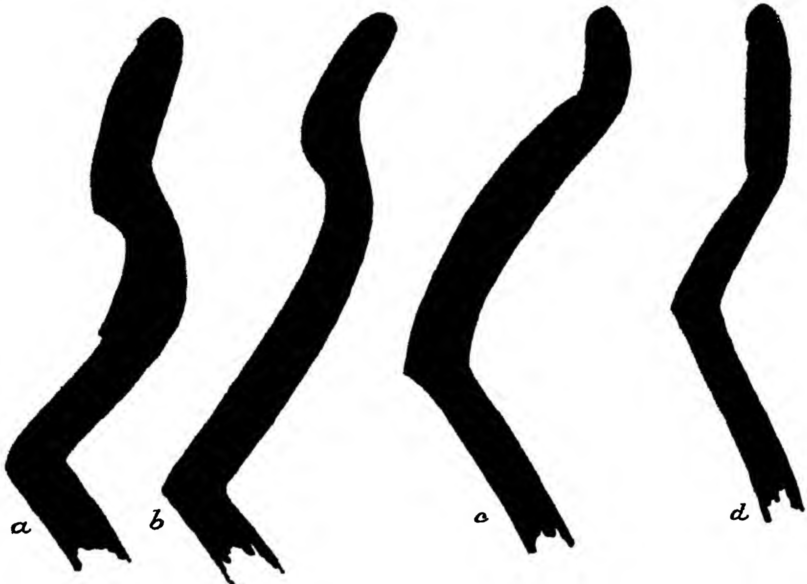


FIG. 18.—Rim sections of polychrome ware Arroyo Malo.

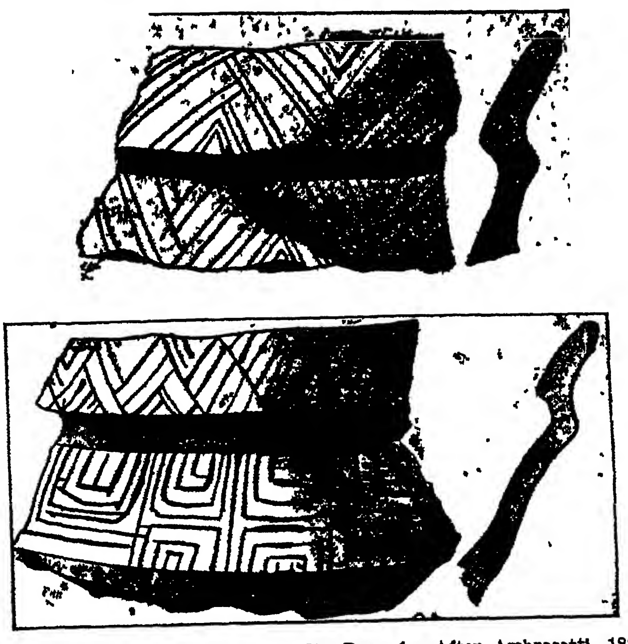


FIG. 19.—Polychrome pottery. Alto Paraná. After Ambrosetti, 1895.

among Guaraní tribes such as the Chiriguano (*150*, Fig. 46, nos. 2, 3) but even by more distant peoples like the Conebo in eastern Peru.[81a]

The elongated and incurved base characteristic of this ware is found both to the west and north. It may be seen in burial urns from the Calchaquí region, notably the provinces of Catamarca (*51*, Figs. 10, 11; *8*, 1. I, no. 29) and Salta (*9*, Fig. 19); it is suggested by the bases of jars

FIG. 20.—Polychrome pottery. Martín García Island. After Outes, 1917, 1918a. Widths 4, 3, 2, in

of the Inca period from Peru; modern vessels of the Conebo Indians of eastern Peru have a similar shape,[82] and similar types are found to the north in such distant lands as Venezuela.[83] The significance of this distribution is not wholly apparent, but this feature appears most characteristically in pottery attributed to Guaraní tribes (Fig. 13, *a*).

[81a] Guide to the Peabody Museum, Pl. 6.
[82] Guide to the Peabody Museum, Pl 6.
[83] Mus. Amer. Ind., Heye Fdn., 4/8919.

The designs on Arroyo Malo polychrome ware are black-line geometric panels placed between red bands. Unfortunately the black paint was unstable and practically always has disappeared, but the red bands have survived often enough to show that this ware was once fairly common. The decorative motives at Arroyo Malo, seen in Pl. X, are elaborations of the chevron, but doubtless other motives were also prevalent. In Fig. 20, we illustrate patterns of this type from Martín García island, of which one is based on the chevron while the others are curved. Similar

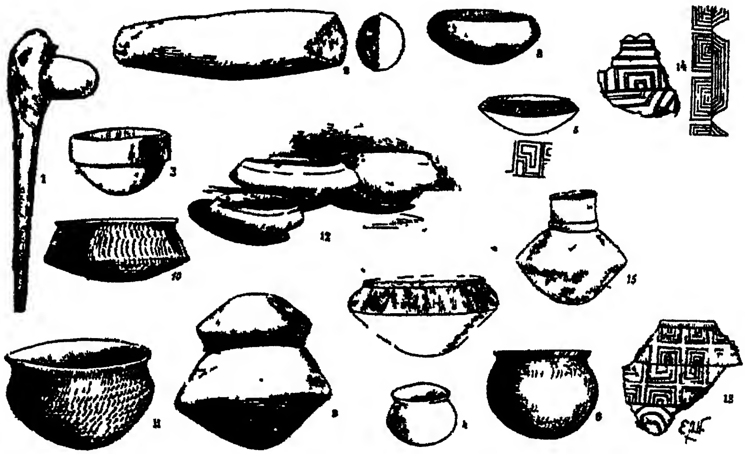


FIG. 21.—Archeological types of the Alto Paraná. After Ambrosetti, 1895.

chevron adornments from the northern Argentine appear in Fig. 19, while No. 15 in Fig. 21 exhibits a curving design comparable to Fig. 20, *c*, from Martín García island. These specimens indicate then that a polychrome ware, uniform in shape of body and rim as well as in design motives, extended from Brazil to the R. La Plata.

Looking farther afield, painted chevron patterns of similar type can be found over much of the southern continent, as well as in Central America. For instance, in the collections of the Museum of the American Indian, Heye Foundation, we note this type of decoration from the Argentine (upper Paraná, lower Paraná, and Diaguita region), Chile (Provinces of Coquimbo and Cautín), Peru (Nasca and Chimbote), Ecuador (Provinces of Chimborazo, Bolivar, Pinchincha, Tungurugua, Imbabura,

and Carchi), Colombia (Department of Nariño), Venezuela (State of Trujillo), Dutch Guiana, Costa Rica, Nicaragua, Salvador, and Honduras. An example from the northern coast of Venezuela, illustrated in Fig. 22, is typical of this class of design in the northern part of the continent. It differs from Guaraní decoration not in the character of the pattern so much as in the quality of the line.

The mass of these designs which we have tentatively grouped together is so great that it is beyond the scope of the present study even to list them with any degree of completeness. Practically all this material at present is undated, but in certain cases it is comparatively ancient, while in others it is recent. We may speculate, however, that such vigorous and widely spread ceramic traits had their origin in the far past, while the

FIG. 22.—Painted bowl from Venezuela. Diam. 5¾ in (6/705).

existence of several such pottery complexes in the New World suggests that several basic types of fictile decoration arose independently in scattered areas. At any rate, the polychrome ware manufactured by Guaraní Indians at the mouth of the Paraná river forms the southern limit of an apparently fundamental class of American pottery patterns.

Fire Dogs

No small objects of pottery were found at Arroyo Malo, but we did discover a number of clay hemispheres five or six inches in height. They usually had a hole in the top and bottom, made by inserting the finger while the clay was still soft, and sometimes they were adorned with simple incised patterns (Fig. 23). In all cases they were found in fragments. We assume that these objects were pot rests or fire dogs. Nordenskiöld (*151*, p. 126, and map 14) has discussed their distribution and locates them principally among natives of the Amazon valley living both north and south of the main river. The Mojos are the nearest of these tribes to the Paraná delta. Nordenskiöld illustrates two types of pot-rests.

One is conical, like the Arroyo Malo type, but the other is a hollow cylinder like those we found at Arroyo Sarandí, illustrated in Fig. 62.

STONE OBJECTS

We have already pointed out that no stone of any kind exists naturally in the Paraná delta, so that all specimens of this material must have been transported there by man—a fact that might make it possible to trace local lines of trade through identification of the provenience of various

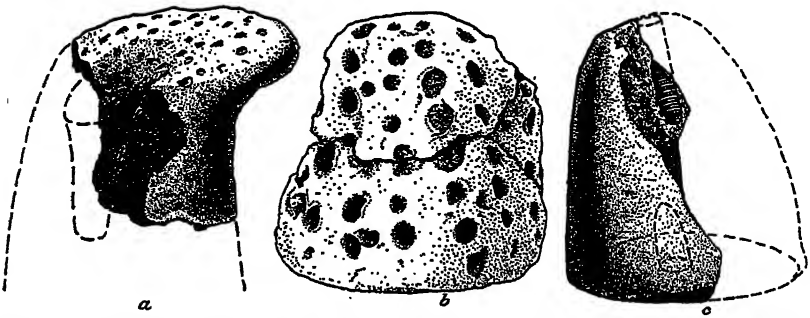


FIG. 23.—Pottery fire-dogs. Arroyo Malo. Heights, 3, 6, 5 in. (14/6653, 6653, 6652.)

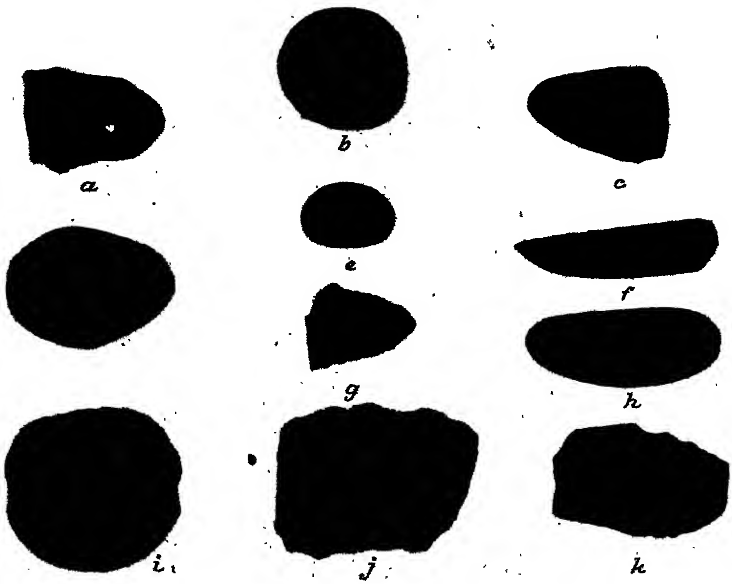


FIG. 24.—Stone chips, scrapers, polishers and bolas. Arroyo Malo. Length of *h*, 2 in. (*a*, *g*, *j*, 14/4847; *b*, *e*, *h*, 4857; *c*, *d*. *f*, *k*, 4854; *i*, 4848.)

types of stone. For instance, our workmen told us that brightly colored pebbles and chips of quartz and agate, found occasionally at Arroyo Malo (Fig. 24) and El Cerrillo, must have come from the banks of the Uruguay.

The stone objects dug up at Arroyo Malo were of the simplest character. We reproduce, in Fig. 25, an axe which is typical of Guaraní cul-

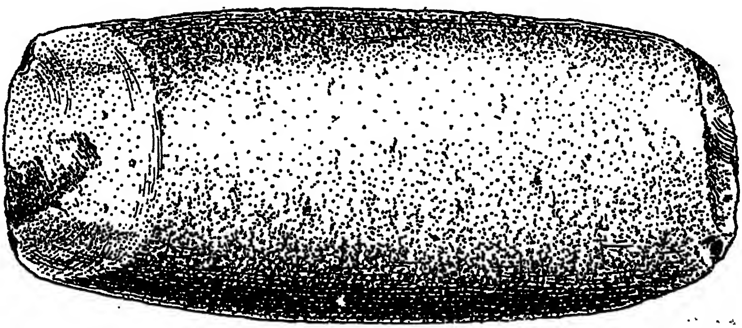


FIG. 25.—Stone ax. Arroyo Malo. Length, 3¾ in. (14/4850.)

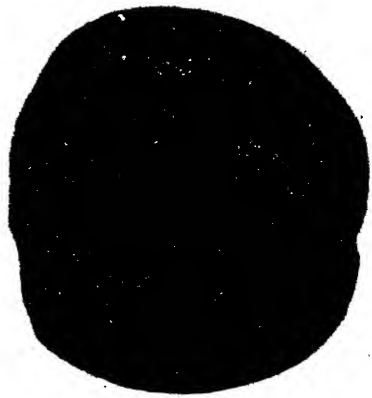


FIG. 26.—Bolas. Arroyo Malo. Diam., 2⅞ in. (14/6646.)

ture. Outes (*175,* Fig. 27, and pp. 176–177) has illustrated an almost identical one from Martín García island, and has commented on the distribution of such axes. Ambrosetti has illustrated an example from the Alto Paraná, which we reproduce in Fig. 21, *1, 2.*

Two fragmentary bolas (Fig. 24, *i,* and Fig. 26) came to light during our excavations, one well made with a broad groove, and the other roughly shaped and having a narrow groove. This weapon is not attributed to the Guaraní of the delta by early historians, which raises a suspicion that

the examples we found might have been dropped by some other people. However, Outes (*175*, Fig. 28) obtained a grooved bolas with Guaraní archeological remains on Martín García island, so that it seems probable that these Indians really did make use of the bolas.

Hammerstones we illustrate in Fig. 27. It will be noted that they have been roughly shaped by abrasion. In one instance (*c*), opposite sides of the stone have been pitted to make possible a firmer hold.

This ends the list of stone objects found at Arroyo Malo, with the exception of rejected chips such as are shown in Fig. 24, *a*, *g*, *j*, *k*. The scarcity of stone is rather surprising, but explainable perhaps by the fact that the habitat of the Guaraní was more or less in the center of the delta,

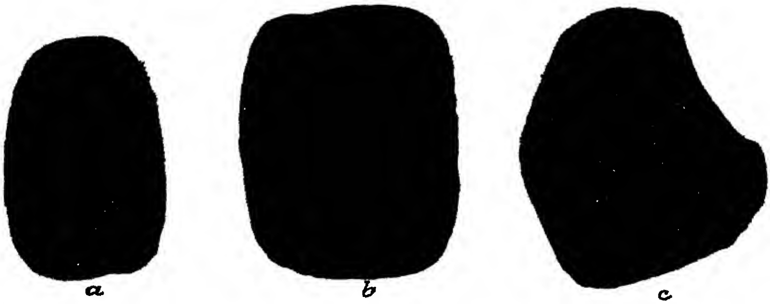


FIG. 27.—Hammerstones. Arroyo Malo. Length of *b*, 3½ in. (*a*, *b*, 14/4852; *c*, 4853).

while hostile tribes controlled the places where a stone supply existed. At all events, most Guaraní tools and weapons must have been of bone, horn, or wood, and of these no trace remained owing to the humidity of the soil.

II.—EL CERRILLO

NATURE OF THE SITE

After work on the Arroyo Malo had been terminated the expedition moved to the south bank of the Paraná Guazú. Our objective was a low irregularly shaped refuse-heap containing burials, situated on the edge of a choked and swampy stream which entered the river opposite the Isla de los Platos (Figs. 6 and 28). This land is known as Lot 161, and the archeological site was called El Cerrillo by the two families living about a mile away. After we had been at work for some time we learned that Dr. Torres had partially excavated the mound in 1905, and had published in 1911 a description under the name "Paraná Guazú, tumulo no.

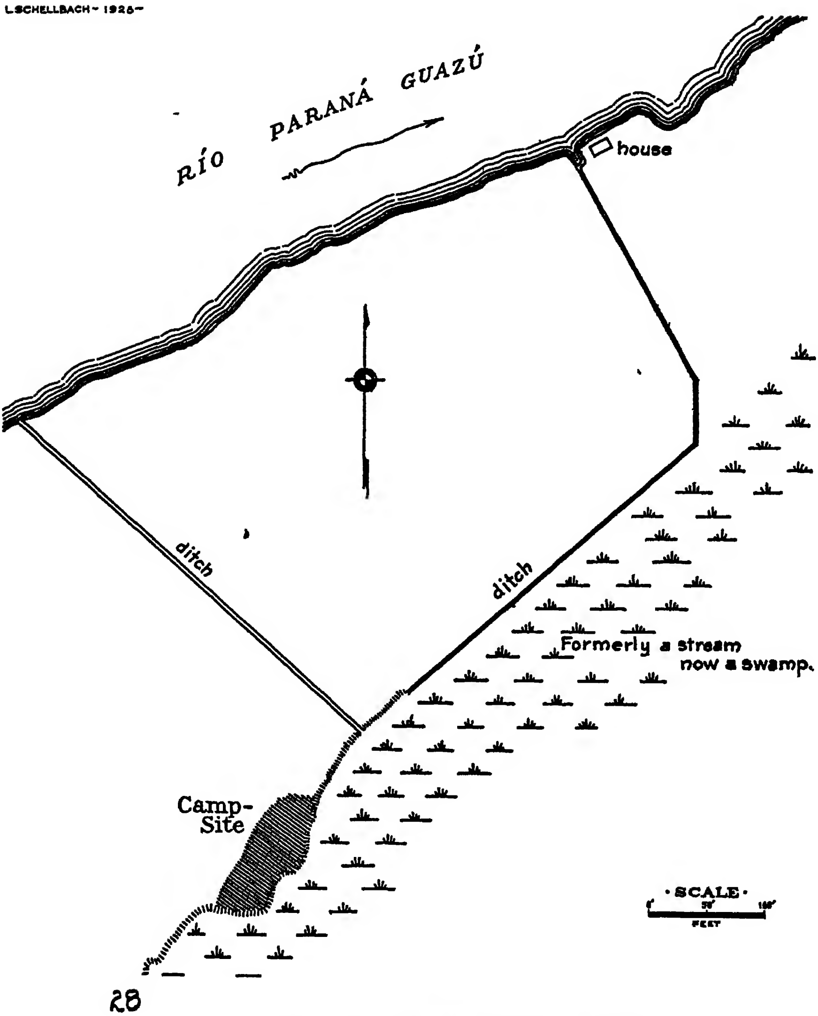


FIG. 28.—Sketch map, locating El Cerrillo campsite.

1." Indeed, it was only by chance that our excavations commenced in an untouched area at the southern edge of the refuse instead of in Dr. Torres' back dirt. In Fig. 29 we show a plan of the mound, while Pl. XI gives two views from the southern end, one taken immediately after clearing and one during the course of excavation.

The campsite stands on ground perhaps a foot or two higher than the general level, above which the mound itself had an extreme elevation of

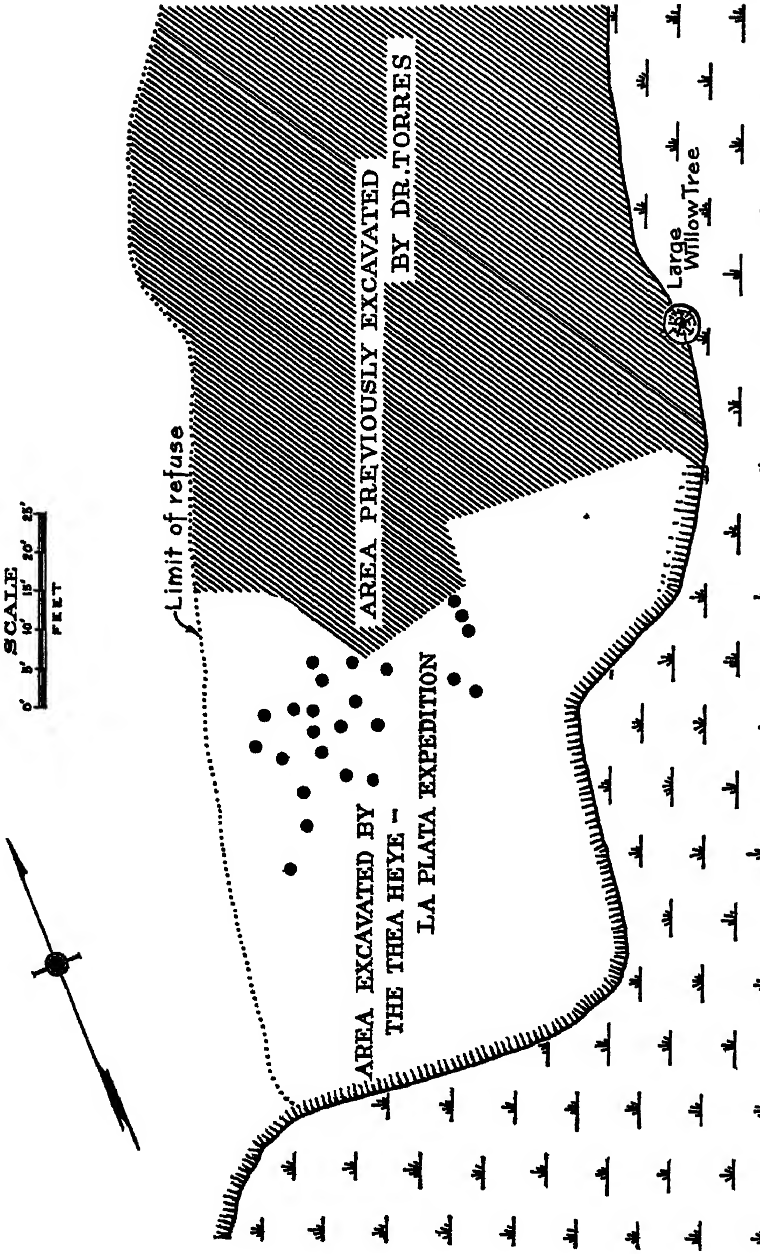


FIG. 29.—Refuse-heap and burial-ground excavated by the Thea Heye–La Plata expedition. El Cerrillo, Argentina. (●—burials.)

three and one-half feet. At times of high water, parts of the surrounding country and the bottom of our trench were inundated, but the top of the mound offered a refuge against the usual small flood. In this respect it afforded much better living conditions than the Arroyo Malo site, though it was not so secure as the location afterward excavated on the Arroyo Sarandí.

The underlying soil at El Cerrillo is the yellow clay found throughout the entire delta. Above this, human remains lay in soil blackened by carbonization and decay of organic materials. As excavation progressed there were revealed a great number of lenticular ash–pockets, which testified to the slow upbuilding of the living surface (Fig. 30). Several hearths of baked clay also came to light.

FIG. 30.—Cross-section of El Cerrillo refuse heap.

The remains encountered during excavation included a great number of potsherds and animal bones, mainly of nutria, carpincho, and deer, which, together with fish, formed the principal diet of the inhabitants. Many implements of bone and antler also were recovered, as well as a few artifacts of stone. Finally, we uncovered twenty-three skeletons, some of which were very fragmentary. As Dr. Torres had previously secured twenty-one skeletons at the northern end of the mound, the total number of burials at El Cerrillo was forty-four. At the request of Dr. Torres, all human and animal bones were shipped to the La Plata Museum.

As no objects of European origin were found we believe the site to antedate the coming of the Spaniards. At the same time, the remains do not differ radically from those of other places in the delta where European objects have been found. Hence there is no reason for thinking that the site dated from long before the Conquest.

From the situation of this site and its probable age we judge that the inhabitants were Chaná or Chaná–Mbeguá.

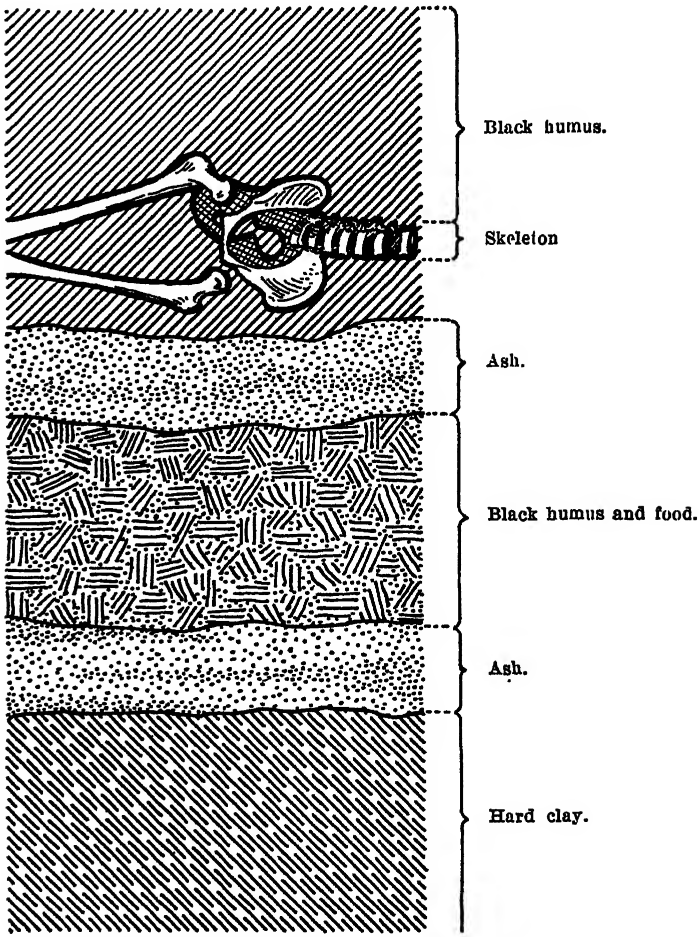


FIG. 31.—Section of a typical grave. El Cerrillo.

BURIALS

El Cerrillo burials were clearly of a secondary character, and of the twenty-three we uncovered only four were entire and articulated. In several instances skeletons were complete, but the bones lay in unnatural positions which could not have been induced by earth pressure. For instance, the arms or legs sometimes had been reversed end for end, while skulls had been placed on top of or beside the body. More frequently, however, some of the bones were missing. These conditions we illustrate in Pl. XI, *b*, where twelve burials are seen, of which only three were articulated and entire. In the foreground are a pelvis and two femora, while

beyond and to the right are two complete skeletons. At the extreme left lies another complete skeleton. Just in front of the shovel is a body lacking the head, but with the lower jaw on the sternum. The remaining burials are disarticulated and incomplete. From this evidence we judge that after death bodies were exposed to the air for a long time, and eventually what was left of them was buried. Historical accounts of secondary burial among the eastern Chaná have received notice on page 115. Skeletal remains at El Cerrillo were tumbled into the grave in disorder, but it was also manifest that the soul of the deceased had been provided for materially, and that some ceremony had taken place at the moment of interment.

A typical grave, of which we illustrate a section in Fig. 31, consists, first, of a grave shaft through the refuse as far as or into the subsoil. In the bottom of the pit a great fire was kindled and permitted to consume itself, and on the ash a thick layer of food was deposited. This included meat, fish, shellfish, and vegetal material, the last too badly rotted for identification. On top of the food-offering a fire was again kindled, which burned to ash, and on this were cast the human bones. Finally the top of the grave pit was filled.

Offerings of artifacts were rare. In several cases we encountered traces of red paint just under the body. In three graves there was an unusual quantity of potsherds, possibly placed there purposely. Twice we found caches of stone chips and nuclei in the food layer. Bone, antler, and stone implements were noted with nine out of twenty-three bodies. In certain cases similar objects occurred in the refuse near skeletons, but we could not be sure that they were funeral offerings purposely placed with the dead. We append a table analyzing the burials.

POTTERY

A large amount of pottery, consisting not of complete vessels but of sherds, for the greater part fire-blackened and sooty, was recovered at El Cerrillo. The paste employed varied in color from brown to a yellow-gray, and a few sherds were dull red, possibly as a result of firing at a higher temperature than customary. In general, firing was complete from wall to wall, or at any rate repeated use of the vessels for cooking had resulted in complete firing. Fine sand and sometimes shell had been used for tempering, and both interior and exterior walls, though burnished, feel rough to the touch. Although there is no painted decoration or slip, many pieces are ornamented with incised patterns. This ware is

TABLE V

Field catalogue no.	1, 2 [a]	3	4, 5 [a]	7, 8 [a]	9	10	11	12	13	14, 16 [a]	17	18	21	26	23	24	22, 27, 28 [a]
Incomplete skeleton	++	+	+	++	+	.....	+	+	.....	++	.....	.....	+	.....	+	+	+++
Disarticulated skeleton	++	.....	++	++	+	+	+	+	.....	+	.....	.....	.....	.....	+	+	++
Head direction	W	E	E	?	?	E	?	?	S	E	N	E	E	N	?	?	E ? ?
Face direction	UP	?	N	?	?	S	?	?	E	UP	W	S	?	?	?	?	?
Vegetal food	+	+	+	+	+	+	?	?	+	+	+	+	.....	?	?	?	+
Animal food	.....	.....	.....	+	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Fish-bones	.....	.....	.....	+	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Shells	+	.....	+	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Ash layer	+	+	+	+	+	+	?	?	+	+	+	+	+	?	?	?	+
Red paint	.....	.....	.....	+	.....	+	+	+	+	.....	.....	.....	+	.....	.....	.....	.....
Stone objects	.....	.....	.....	+	+	+	.....	.....	.....	.....	.....	.....	+	.....	.....	+	.....
Bone objects	+	.....	+	+	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	+	.....
Horn objects	+	+	+	.....	.....	.....	.....	.....	.....	.....	.....	.....	+	.....	.....	+	.....
Sherd cache	.....	.....	.....	+	.....	.....	.....	.....	+	.....	.....	.....	+	.....	.....	.....	.....
Lumps of clay	+	.....	+	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

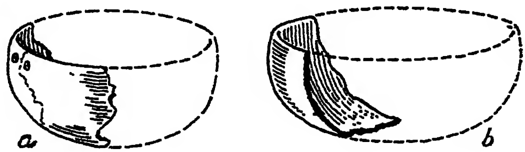
Analysis of Burials at El Cerrillo.

[a] Multiple burials in a single grave.

far superior in strength to the pottery of Arroyo Malo, but inferior to that of the Arroyo Sarandí.

Practically all the pieces recovered were fragments of small bowls such as appear in Fig. 32, and large vessels were not in evidence. In most cases the lips were rounded and the outline unmodified, although sometimes the lip had been everted (Pl. XIV, *g*), flattened (Fig. 33), or notched (Pl. XIV, *b*), the last characteristic being typical of Querandí

FIG. 32.—Bowl types. El Cerrillo. Restored diams., 6⅛, 5½ in. (14/7116.)



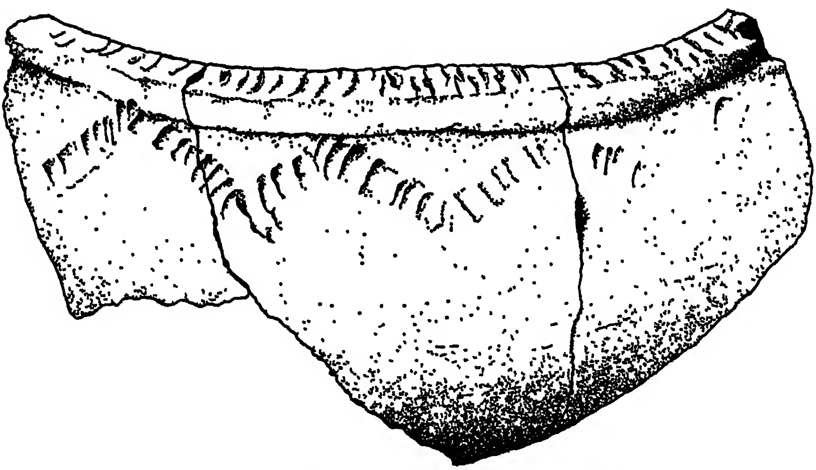


FIG. 33.—Fragment of incised bowl. El Cerrillo. Length, 5⅝ in. (14/7117.)

pottery from the Río Luján. We found two fragmentary jars, of which one (Fig. 36) had a flaring rim, while the other (Pl. XIX, *a*) had an incurved rim with a sunken band encircling it, a form suggesting Guaraní jars such as that in Pl. VI, *b*. No handles were present, but one sherd had a small pierced lug (Fig. 34). The only really unusual specimen, shown in Fig. 35, had been pierced with a great number of holes. This may have been part of a steaming dish such as Nordenskiöld (*150*, pp. 51–55, and Figs. 16*a* and 16*b*) describes among the Chané and Mataco-Vejos.

Decoration takes the form of incised geometric patterns, which usually are placed as encircling bands on the outer wall of the vessel. If the lip

had been flattened it sometimes carried a slight design (Fig. 33), and in one case (Fig. 36) the inner side of a flaring jar rim had been incised.

FIG. 34.—Sherd with lug. El Cerrillo. Height, 1⅓ in. (14/7118.)

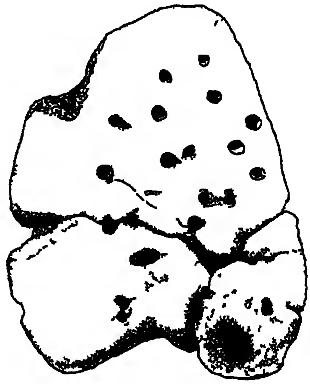


FIG 35.—Fragment of perforated vessel. El Cerrillo. Length, 2 in. 14/7114.)

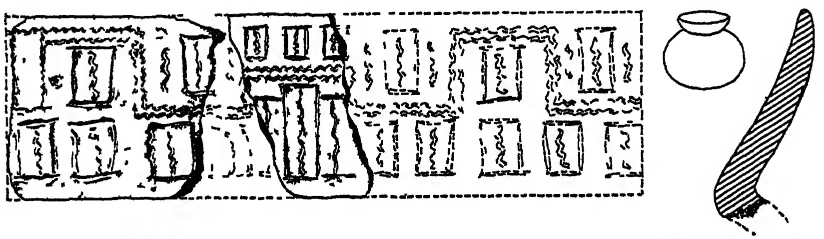


FIG 36—Incised pattern from inner rim of jar. El Cerrillo. Width, 1⅞ in. (14/7117.)

Several distinct techniques for incising the patterns may be noted, as follows:

1.—*Waving lines of even width,* cut with a blunt instrument (Pl. XII, *a–d*). This type of line is characteristic of the lower delta as a whole and of this site in particular.

2.—*Waving lines of varying width* (Pl. XII, *i*), made by a chisel-like instrument with the blade held always on the same axis. The result is similar to writing with a broad-bladed pen.

3.—*Stippled lines* (Pl. XII, *h,* and Fig. 38, *a*), that is to say lines formed by a continuous series of punctures. While this type occurs southward into Patagonia, it is especially common farther up the Paraná in the vicinity of Santa Fe (Pl. XXVII, nos. 39 and 40).

4.—*Dotted lines,* formed by a series of dots (Pl. XIV, *j, k*). This was very common at El Cerrillo, but rare on the Arroyo Sarandí. As one goes upstream toward Santa Fe, the dots become much larger and usually are square or triangular (Pl. XXVII, nos. 41 and 43). To the south, pottery found near Quilmes and Lake Chascomús is characterized by very fine dots (Pl. XXVII, No. 15).

5.—*Hatched lines,* consisting of a series of short parallel lines. These may be broad and closely spaced (Pl. XII, *e, f*), or they may be narrow and widely spaced (Pl. XII, *g*). Sometimes the lines were made with a

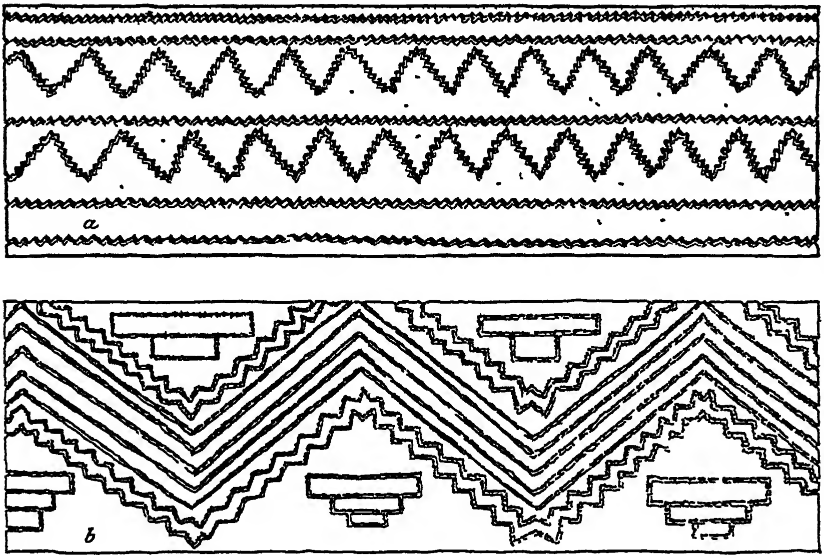


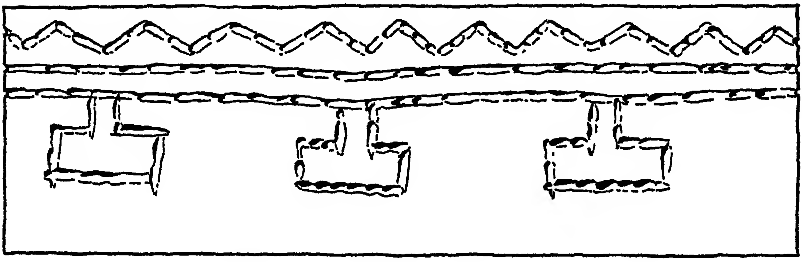
FIG 37—Incised designs El Cerrillo.

tool as in the examples mentioned, but not infrequently they appear to have been made with the finger-nail as in Pl. XIX, *d, e.* This technique is common at El Cerrillo, but not elsewhere in the delta. It is found far to the south in the San Blas peninsula (Pl. XXVII, no. 11). Hatched lines made with a tool of some kind occur throughout the entire range of incised pottery from Patagonia northward.

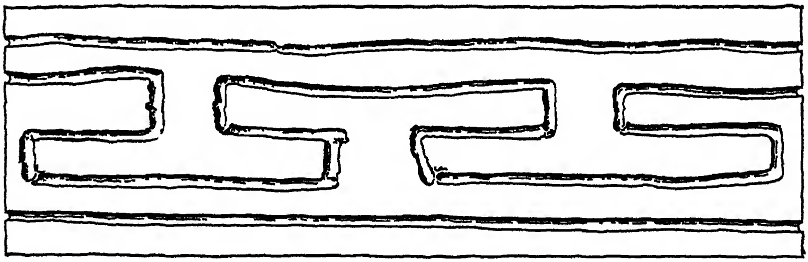
The nature of the designs themselves may be seen in the accompanying illustrations, and there is little that we can add in the way of verbal description. In Pl. XII we have grouped a series of parallel line decorations which depend for their effect chiefly upon the quality of the line. In Pl. XIII there appear simple zigzags, which, when placed in contact (*b, f,*

g, h), form rows of diamonds. Plate XIV illustrates an additional variety of zigzag motives, which develop into triangles pendent from encircling bands (*j, k*). The most elaborate example of this motive, shown on Fig. 37, *b*, consists of large zigzags flanked by lines repeating the main pattern on a smaller scale.

In Pl. XV we show the development of the pendent triangle into pendent loops, while Pl. XVI exhibits more variants of this motive. It will be noted that in certain cases (Pl. XVI, *a, b, d*) the principal pattern has been executed by a continuous incised line and that the interior has



a



b

FIG. 38.—Incised designs. El Cerrillo.

been set off by smaller lines or dots. This method of decoration suggests the usual type of New World polychrome pottery, on which the major patterns are outlined in black paint, while the enclosed spaces are filled with color. It runs from the Pueblo area in North America to the Aconcagua valley in central Chile. On both continents the polychrome technique is reproduced in incised designs. For instance, such incised designs are common throughout the lower delta region, and they extend southward, if not to southern Patagonia, at least to the San Blas peninsula. To the north, similar decoration has been found by Nordenskiöld on the San Francisco, a tributary of the Río Bermejo (Pl. XXVII, nos. 45 and

46), and it appears constantly in the intervening territory. In the Diaguita area similarly treated incised designs occur, but the patterns themselves are quite different, for at times they are derived from Peruvian art, especially pottery of Nasca and Tiahuanaco. In North America there are two comparable methods of incised decoration: dot- or line-filled outline and dot- or line-filled background. Though examples are found as far north as Michigan, they are particularly common in the southeastern United States, especially in Florida, Georgia, and Kentucky. We have also seen specimens of these techniques distributed sporadically between the North and South American centers, as for instance, from the Cauca valley in Colombia, from the Province of Chiriqui in Panamá, and from the southern coast of Porto Rico.

To return to El Cerrillo, Pl. XVII illustrates a design group based on the terraced fret, and further developments appear in Pls. XVIII and XIX, *e*. Two rather simple variants of this motive, seen in Fig. 38, have a wide distribution, for similar designs are known as far as southern Patagonia. Another group of patterns, in Pl. XIX, is based on small rectangles, formed by dots or incised lines, which are assembled to create a checkerboard, a pattern which plays an important part in the painted decoration of Tehuelche skin robes. Similar designs occur on Diaguita vessels from Chile.

Enough has been said to indicate the nature of El Cerrillo pottery and to suggest that it has affiliations over a wide area both to the north and to the south. We postpone consideration of the more general problems until we shall have described the incised pottery excavated at Arroyo Sarandí.

STONE OBJECTS

Since no stone exists naturally in the delta country it is to be expected that the inhabitants had few implements of this material, all of which had to be obtained at a great distance. At El Cerrillo a number of chips and of small unworked pebbles were found with the burials. The commonest tools were hammerstones, showing marks of abrasion, which perhaps had been used for splitting the longbones of animals. In certain cases, such as the specimens illustrated in Fig. 39, these stones had been pitted on each side in order to afford a firmer grip. Another find was a stone ball, shown in Fig. 40, which indicates that bolas were employed by the inhabitants of this site. Another isolated find (Fig. 41) was a chipped quartz arrowpoint, the only chipped blade encountered. In type it conforms to a blade from Arroyo Sarandí (Fig. 65), to arrowpoints

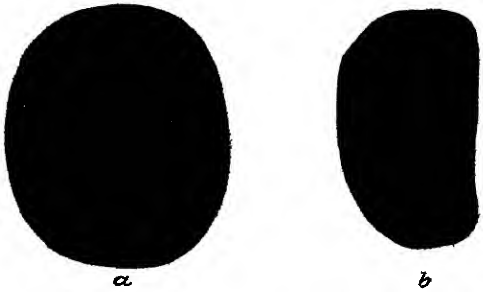


FIG. 39.—Pitted hammer-stones. El Cerrillo. Length of *a*, 3¼ in. (14/4816.)

FIG. 42.—Fish-spine awls. El Cerrillo. Lengths, 2¾, 6¼ in. (14/4791.)

FIG. 40.—Stone ball. El Cerrillo. Diam., 1½ in. (14/4823.)

FIG. 41.—Arrowpoint. El Cerrillo. Length, 1½ in. (14/4820.)

FIG. 43.—Bone needles. El Cerrillo. Length of *a*, 5 in. (14/4818, 4805, 4814, 4810.)

from Patagonia (*164*a, p. 380), and to others in the collection of the Museum of the American Indian, Heye Foundation, from the Province of Salta. Outes (*166*, Figs. 11, 12) has illustrated similar blades from Cochicó in the Province of Mendoza.

BONE AND HORN

Owing to the scarcity of stone, the inhabitants of El Cerrillo had to depend on bone and wood for most of their implements. It seems natural to suppose that they employed wood for many purposes, but of this no trace remained. In the Chaco, where stone likewise does not exist, wooden knives have been used until recently,[88a] and it seems probable that they were employed in the Paraná delta, as no knife–blades occurred among the archeological remains.

One of the commonest tools encountered was the bone awl, of which there were several types. In Pl. XX we ilustrate a series fashioned from the longbones of deer with the articulation serving as a handle. Fig. 42 shows awls made from fish–spines, which, it will be recalled, were used by the Minuané to pierce their arms and legs during the very painful ceremony of mourning. In Fig. 43 is shown a group of awls or needles of a more slender type. One of these (*b*) has a hole drilled through the base, but it does not seem possible that this was used for sewing, because the width of the base is too great. Tools such as we describe are common to most hunting peoples, and exhibit little individuality or character.

A curious type of instrument made of antler points appears in Pl. XXI. Our workmen promptly named them "whistles," while Dr. Torres (*225*), who found several examples both at El Cerrillo and at other sites in the delta, believed them to be harpoon–points. Nordenskiöld (*153*), however, has shown that they served for stringing fish, and that they are still in use among certain tribes of the Chaco. We reproduce in Pl. XXI his illustrations of a similar modern example collected among the Mataco, and a comparable specimen of wood from the Ashluslay. The delta sites where similar finds have been made include El Cerrillo, Arroyo Sarandí (Pl. XXVI), Paraná Guazú (tumulo II) (*225*), and Brazo Largo (tumulo I).

Bone points intended for use as spearheads are illustrated in Figs. 44 and 45. They are very similar to the larger awls, except that the base is open for hafting. In one case there is a small hole in the side of the

[88a] Nordenskiöld (1919, p. 63) states that wooden knives were known to the Choroti, Ashluslay, Tapiete, Lengua, and Mataco.

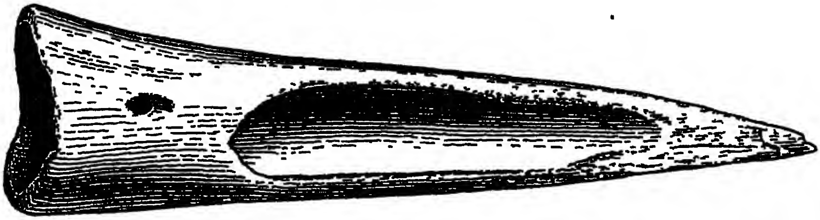


FIG. 44.—Bone spearpoint. El Cerrillo. Length, 3½ in. (14/4793)

base, which probably served to secure the head to the shaft by means of a rivet. This form of spearhead has wide distribution to the northward in the Amazon valley. The Museum of the American Indian has a splendid collection made among the Caraya tribe.[84]

In Fig. 47 we show a smaller and a lighter type of bone point which we believe was used for tipping arrows. Arrowpoints in the Museum from Tolombon in the Province of Salta repeat this form in stone,[85] while bone points of this shape have been recovered in the Province of Catamarca (*7*, Fig. 37; *51*, Fig. 25).

Arrowshafts at El Cerrillo, being made of wood, have not survived, but tools used in their fabrication were found fairly frequently. As seen in Fig. 48, these consist of Y's cut from a branching deer antler, with a hole pierced at the point of juncture, in which the arrowshaft was inserted, there to be straightened by pressure. This tool has world-wide distribution. It was first noticed by archeologists among finds of the Magdalenian period in Europe, where much speculation arose as to its use, and it received the fanciful name of *baton de commandement.* The actual purpose for which it served—the straightening of arrowshafts—is not, however, a subject of speculation, but of observation among primi-

FIG. 45—Bone spear point. El Cerrillo. Length, 2¾ in. (14/4826.)

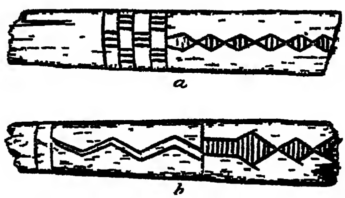


FIG. 46—Carved bone. El Cerrillo. Length, 1¾ in. (14/4806.)

[84] See Indian Notes, Vol. II, Fig. 43.
[85] Museum of the American Indian, Heye Foundation, 15/2911.

tive people, such as the Eskimo. The great chronological and geographical distribution of this tool gives ground for belief that its presence in South America may not be due to independent invention but to culture transference long ago at the time of the first colonization. In the Paraná delta, Torres (*223*) has described other examples from Campana, while we excavated several specimens on the Arroyo Sarandí, thus showing that they were known to the Querandí.

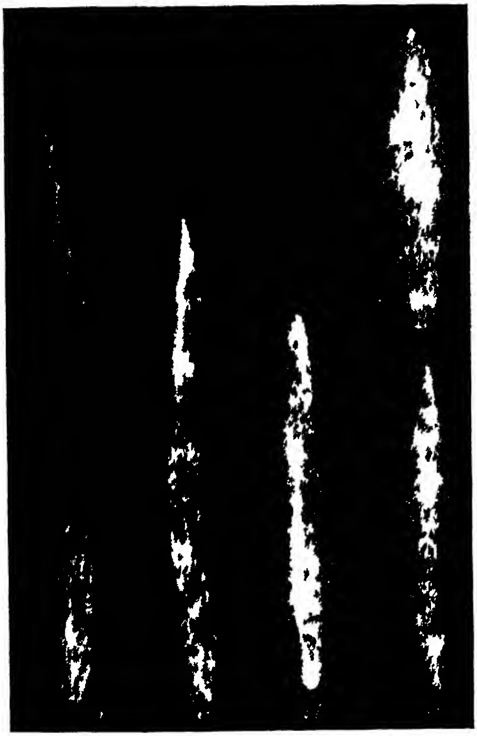


FIG. 47.—Bone points. El Cerrillo. Length of *b*, 4⅛ in. (14/4812.)

Antler punches were common at El Cerrillo. The usual type (Pl. XX, *e, f*) was not decorated, but in a number of cases they were adorned with incised designs (Pl. XXII, *c, d, e*). Similar decoration occurred on pieces of bone (Pl. XXII, *f, g*) which may have served as handles, and also on some of the fish-stringers (Pl. XXI, *c. d;* Pl. XXII, *h*).

The patterns are in general unlike those of the incised pottery, though of the same primitive school of art. They consist usually of hatched or cross-hatched parallel lines. The latter often are enclosed in a band by two parallel lines, while the entire decorated field may be divided into units by lines encircling the instrument. We illustrate all these forms in Pl. XXII, *c–h*, while *b* shows a zigzag decoration more suggestive of pottery motives.

SHELL

Clam-shells were associated with two of the burials at El Cerrillo, and were also found scattered throughout the refuse, but neither Dr. Torres nor the writer encountered manufactured objects of this material.

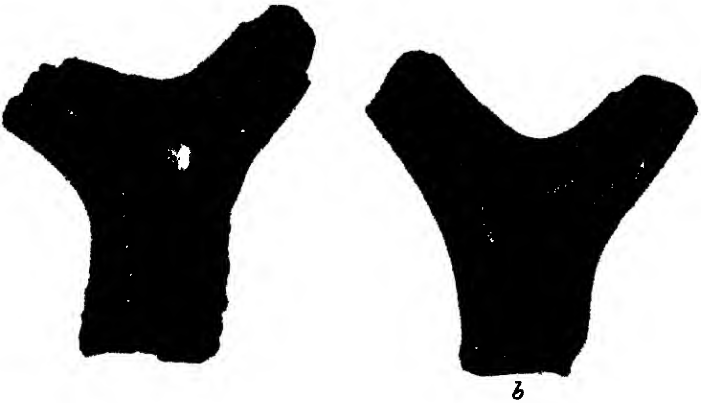


FIG. 48.—Antler arrowshaft straighteners. El Cerrillo. Heights, 3⅞, 3½ in. (14/4827.)

III.—ARROYO SARANDÍ

NATURE OF THE SITE

The last fieldwork undertaken by the Thea Heye–La Plata expedition was the excavation of a refuse-heap and burial-ground fronting the Arroyo Sarandí, an affluent entering the Luján river about six kilometers above El Tigre (Fig. 6). The site is situated some twenty minutes' walk

FIG. 49.—Northern mound from the northeast. Arroyo Sarandí.

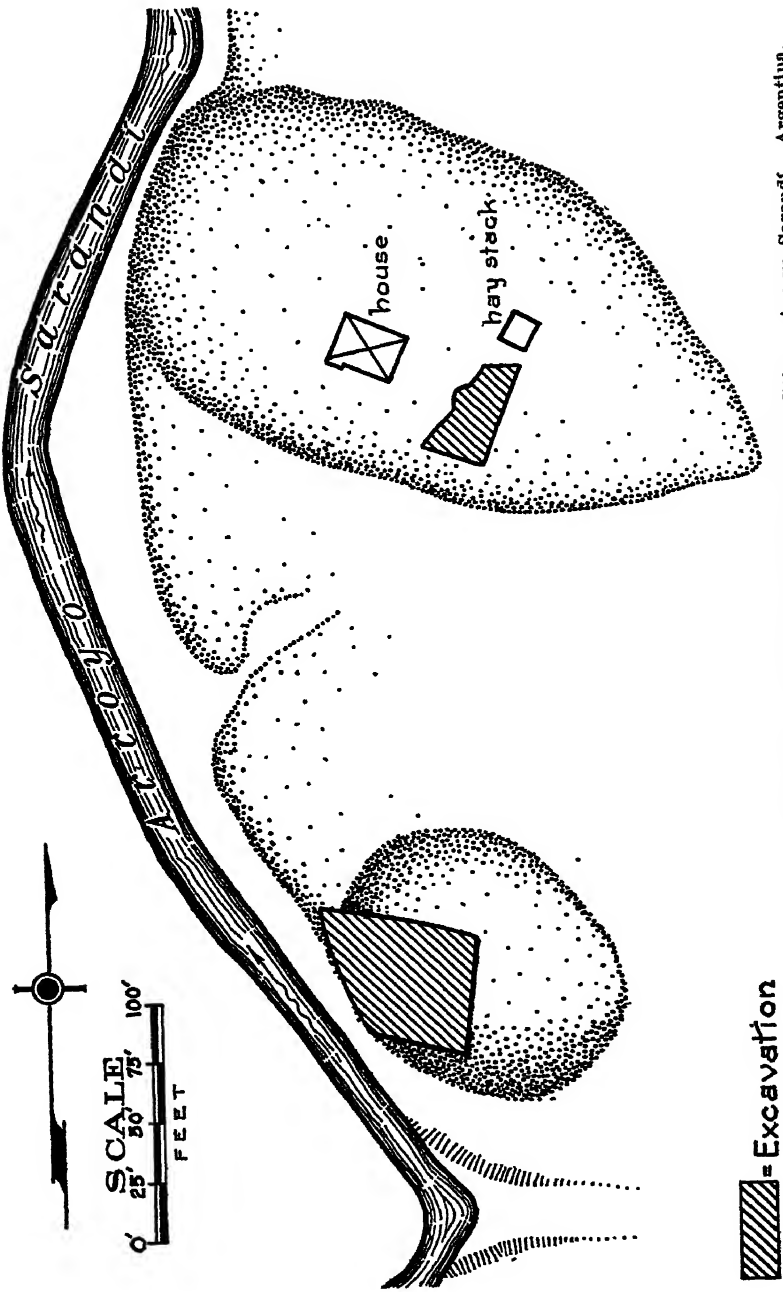


FIG. 50.—Campsite and burial-ground excavated by the Thea Heye–La Plata expedition. Arroyo Sarandí. Argentina.

from the river, on a broad plain which slopes imperceptibly from the delta country to the Pampas. How much above high-water level the camp stood, we cannot say, but the floods of local nature did not penetrate to the spot while we were working there.

The character and extent of the site are revealed in Figs. 49 and 50. It consisted of a thin layer of rubbish covering an irregularly shaped area, marked by two low but pronounced elevations at the northern and southern ends. This deposit nowhere exceeded three feet in depth, and for the greater part averaged less than a foot; cultivation and the tramping of cattle doubtless had reduced the original height.

BURIALS

Our excavation took the form of trenches in the northern and southern elevations. The former yielded a single burial, while forty-one burials were uncovered in the latter. Also many bone tools, in general resembling El Cerrillo types, were recovered, as well as a great mass of potsherds, some pottery pendants, and a few stone objects. Bits of iron rust and cow-bones found at depths varying from four to ten inches dated the remains as largely if not entirely post-Spanish, and also identified the inhabitants as Guazunambí Indians, for this tribe occupied the region during the colonial epoch.[86]

Of the forty-one burials disclosed on the Arroyo Sarandí, 17 were obviously secondary, 17 were primary inhumations at length, 2 were the remains of infants, and the other 5 were too fragmentary for identification. Twenty-one bodies were encountered at a depth of six inches or less, and as a result the bones had in many cases been disturbed by plowing. Thus only 6 of the 17 primary interments were complete, and we assumed that the missing bones, brought to the surface by the plow, had been ground into fragments by cattle. Secondary burials also had suffered from the same cause.

Analysis of the primary burials (Table VI) shows that in 11 cases the body lay chest upward and in 6 instances chest downward. There was a definite tendency to point the head toward the west, for 9 bodies were thus placed; 2 pointed southwest, 3 pointed south, 3 pointed southeast, one pointed east; in no instance did a head point north. The position of the face seemed to be a matter of indifference, and there was no correlation between sex and body-, head-, or face-position.

Secondary burials, as at El Cerrillo, were at times merely confused heaps of bone. We show typical examples disturbed by plowing in Fig.

[86] See pp. 101-102.

TABLE VI

Field catalogue number	Complete skeletons	Articulated but incomplete skeletons	Skeletons lying on back	Skeletons lying on chest	Head direction	Face direction	Depth in inches
1	....	+	+	....	W	....	6
2	....	....	Secondary burial			....	18
3	....	+	•	....	W	....	8
4	....	?	?	....	....	....	14
5	....	+	+	....	W	up	9
6	....	....	Secondary burial			....	....
7	....	+	+	....	W	....	6
8	....	+	+	....	SE	up	12
9	....	....	Secondary burial			....	6
10	....	....	Secondary burial			....	6
11	....	....	Secondary burial			....	12
12	....	....		Infant		....	12
13	....	....	Secondary burial			....	6
14	....	....	....	....	....	....	6
15	....	....	....	....	....	....	12
16	....	+	....	+	S	down	16
17	....	....	....	....	....	....	8
18	....	....	Secondary burial			....	10
19	....	....	Secondary burial			....	6
20	....	....	Secondary burial			....	6
22	....	+	+	....	SW	N	6
23	....	....	....	....	....	....	6
24	....	....	....	....	W	up	14
25	+	+	+	....	SE	up	8
26	....	+	....	+	S	E	6
27	....	....	Secondary burial			....	6
28	....	....	Secondary burial			....	6
29	....	....	Secondary burial			....	4
30	....	....	Secondary burial			....	8
31	....	+	+	....	E	S	6
32	....	....	Secondary burial				6
33	+	+	....	+	SE	N	8
34	....	....	....	Infant	....	....	....
35	....	+	....	+	S	....	8
36	+	+	+	....	SW	N	12
37	+	+	....	+	W	up	6
38	....	....	Secondary burial			....	6
39	....	....	Secondary burial			....	6
40	....	....	Secondary burial			....	6
41	....	+	+	....	W	....	6
42	+	+	....	+	W	S	6
43	+	+	+	....	W	up	12
Totals.	6	17	11	6	....	....	Av. 8″

Analysis of Burials at Arroyo Sarandí.

I,

a

b

c

FIG. 51.—Primary (*a*) and secondary (*b*, *c*) burials. Arroyó Sarandí.

51, *b*, where parts of nine skeletons are illustrated. In *c* of the same illustration there appears an extreme case of intermingled bones, which proved impossible to sort into individual sets. As this lay at a depth of eighteen inches, the bones had evidently been placed in the ground as discovered and had not been disturbed by plowing, unless this ossuary represents a modern reinterment of bones brought to the surface.

Secondary burials at Arroyo Malo and at El Cerrillo differ from those on the Sarandí, in the presence of funeral offerings at the two first-named sites. At Arroyo Sarandí no artifacts or food-offerings accompanied burials of either type, with the single exception of shell beads, shown in Fig. 69, placed around the neck of a woman. It is evident then that, while secondary burial was practised by the inhabitants of the three sites investigated, nevertheless funeral rites of individual character make it possible to distinguish the remains in each case.

Little can be said about the relationship between primary and secondary burials at Arroyo Sarandí. Quite naturally one suspects that a time element is involved. Although positive evidence is lacking, owing to the dearth of mortuary offerings, it seems possible that the secondary burials represent unmodified native custom and that the primary interments came about as the result of Spanish missionary efforts. Many instances of similar changes in funeral customs among Indian tribes could be cited. However, primary burial of the body face downward is not a Christian custom.

POTTERY

No complete pottery vessels were secured on the Arroyo Sarandí, but a great number of potsherds were unearthed, which may be classified as follows:

1.—Buff ware,
2.—Red ware,
3.—White ware,
4.—Red-line ware.

The clay for all these types is the same. It is homogeneous, smooth, and greasy to the touch—somewhat like the yellow Hopi clay—so that sherds from this site can usually be distinguished by feeling them. In color it varies from beige to slate-gray. Tempering consists usually of rounded pebbles, which often protrude through the surface as seen in Fig. 52, but in some instances the concretions which form around roots throughout the delta had been ground up and used for this purpose, as at Arroyo Malo. All vessels were carefully burnished, and firing—unlike that of other pottery of this region—was so complete that the color is uniform from wall to wall. In short, this pottery, though crude, is hard and well made.

FIG. 52.—Restored bowl. Arroyo Sarandí. Diam., 10¾ in. (14/7124)

Buff ware with or without incised decoration is much the most common. Red ware and white ware consist of the same clay, concealed by a thin chalky slip which can be easily removed with a knife. Red-line ware had simple geometric designs painted with the same material as the red ware slip. Only a few examples of these three last wares were found, and it seems probable that many pieces had lost their identity because the pigment had peeled off in the ground. At any rate, this site marks the southern limit on the Atlantic coast of South America both of slips and of painted pottery.

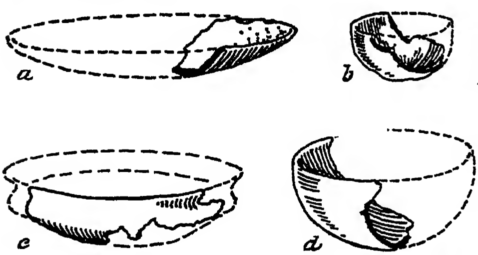


FIG. 53.—Pottery fragments. Arroyo Sarandí. Restored diams., 4¾, 1¾, 8⅛, 8¾ in. (14/7121, 7129, 7123, 7130.)

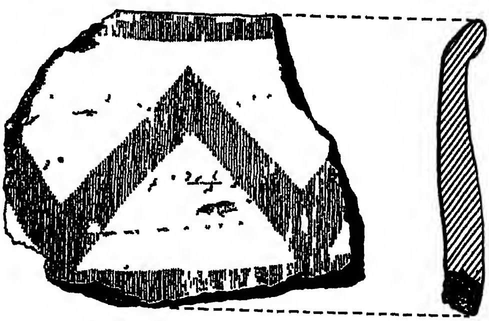


FIG. 54.—Painted sherd. Arroyo Sarandí. Length, 2½ in. (14/7123.)

Shapes are simple, and by far the commonest is a hemispherical bowl with unmodified outline (Figs. 52 and 53, *b*, *d*). There also are slightly curved plates (Fig. 53, *a*). In a few cases the rims are somewhat outcurved in a manner suggesting Guaraní ceramics (Fig. 53, *c*), and there are some pieces with slightly everted lips (Pl. XXIII, *d*). Notching of the lips is a typical though not a constant feature of Sarandí pottery, ac-

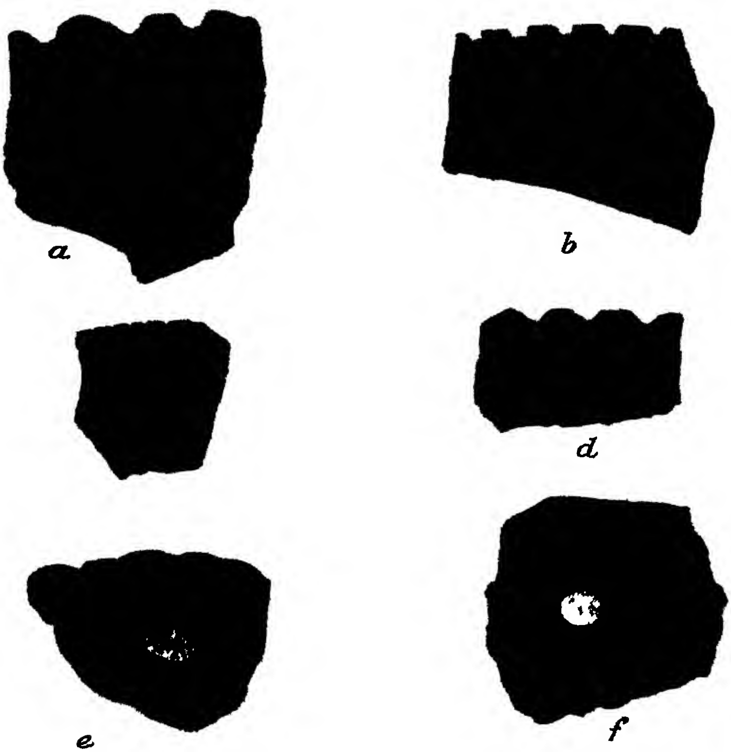


FIG. 55.—Rim fragments. Arroyo Sarandí. (14/7119.)

complished sometimes by modeling with the fingers while the clay was still plastic (Pl. XXIII, *d*), but more often by cutting after the vessel had been fired. The notches, as shown in Fig. 55, may be square, rounded, or of V shape, and there is considerable variation in size. A few of the bowls had been provided with short spouts, set close below the lip (Fig. 55, *e*, *f*). One sherd (Fig. 57, *a*) exhibited a series of holes drilled parallel to and about

half an inch below the lip. Perhaps this represents part of a steaming vessel such as is used farther to the north and which Nordenskiold (*150*, pp. 51–55, Figs. 16*a*, 16*b*) has described among the Chané and Mataco-Vejos. Perhaps these holes served to attach small shell ornaments, as was done by the Mbayas (*199*, I, p. 271). Drilling of pottery to repair cracks is common.

The usual decorations are simple incised geometric patterns, and the normal field for embellishment is the outer rim, but sometimes the inner rim was chosen (Pl. XXIV, *e*), or both rims were decorated (Pl. XXIV

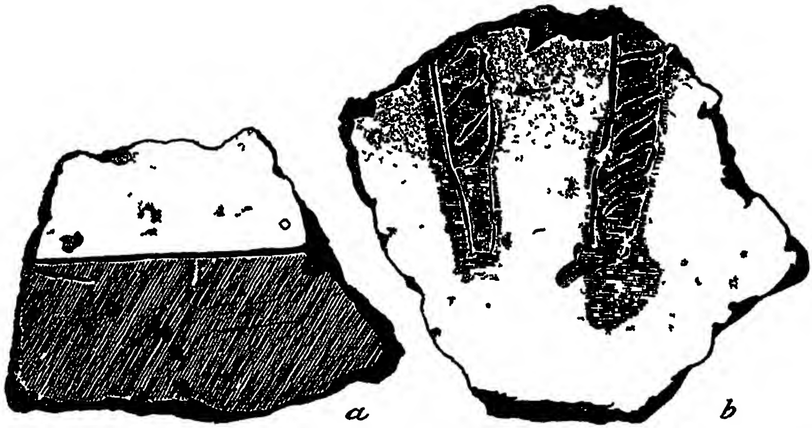


FIG. 56.—Sherds with color separation by incising. Arroyo Sarandí. Length of *a*, 2½ in. (14/7123, 7120).

d, *d′*, *f*, *f′*). Three types of lines may be noted. First, there are simple lines cut by a continuous movement of a pointed tool. Second, there are stippled lines formed by punching a series of contiguous dots (Pl. XXIII, *a*, *c*, *d*). Finally, lines are formed by a series of separate dots (Pl. XXIV, *d*, *f*). Among the supposedly Querandí sherds from Quilmes and Lago Chascomús, pictured by Outes and reproduced in our Pl. XXVII, there occur lines of extremely fine dots and also designs cut in continuous outline but filled with small dots in a manner suggesting polychrome pottery. Neither of these techniques appeared in Sarandí wares.

The patterns employed consist primarily of zigzags, either by themselves (Pl. XXIII, *d*), in tandem (Pl. XXIII, *c*), or set between parallel lines (Pl. XXV, *d*). There are also more elaborate designs, such as frets or terraces, and other motives of a strictly geometric character (Pl.

XXIII, *a, b,* and Pl. XXV, *a, b*). Finally, there is a group of erratic patterns of uncertain line and of no typical form (Pl. XXIV, *a, d', e, f*).

A few examples were found of color separation by incising (Pl. XXV, *b,* and Fig. 56), a technique which has a distribution almost as great as painted pottery, although it does not always appear with the latter. We have noted it on vessels from the United States (Tennessee and Arkansas), Mexico (Pueblo and the Federal district), Guatemala (Departments of Quezaltenango, Retaluleu, Chimaltenango, Quiché, and the Petén), Salvador (Cerro Zapote and Quelepa), Honduras (Ulua valley), Nicaragua

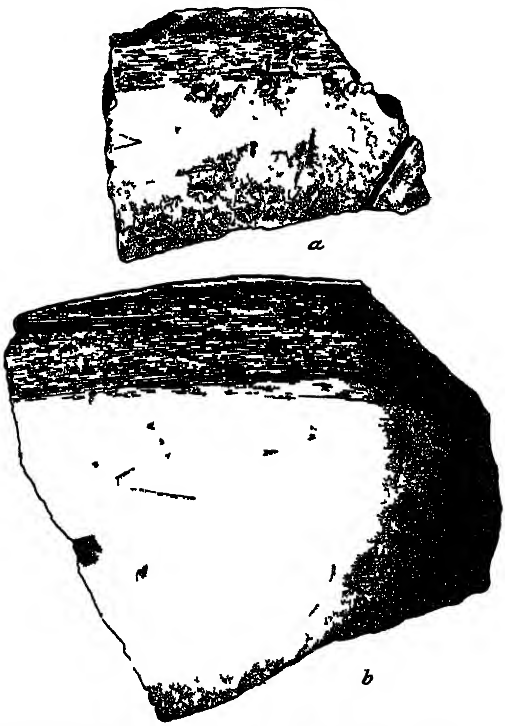


FIG 57.—Painted sherds Arroyo Saiandi. Length of *a*, 2½ in (14/6669, 7120.)

(Guacatepe), Costa Rica (Nicoya peninsula), Panamá (Province of Chiriquí), Ecuador (Province of Narino), the Lesser Antilles (St. Vincent, Grenadines, Carriacou, and Trinidad), and on modern vessels of the Guaycurú Indians. This wide distribution—and the list we have given is by no means complete—indicates that color separation by incising is an ancient technique of pottery decoration, which also is established by its presence on the "Archaic" cultural level among stratified remains in the

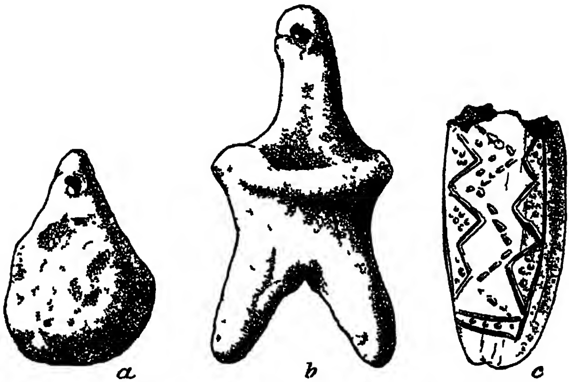


FIG. 58.—Pottery pendants. Arroyo Sarandí. Length of b, 2 in. (14/4785, 4786, 4787.)

valley of Mexico.[87] It is not known in the more detailed ceramic series of the southwestern United States.

A few fragments of pottery with simple painted adornment were found on the Arroyo Sarandí. This decoration usually formed a wide band encircling the outer rim of bowls which had been painted red on the interior (Fig. 57). In Fig. 54 we illustrate a fragment embellished with a zigzag between parallel lines, painted in a style very similar to a sherd discovered by Outes (*175*, Fig. 23) on Martín García island in the R. La Plata. These specimens, the southernmost examples of painted pottery decoration in eastern South America, are so simple that one cannot attribute them to any definite school of design, yet it seems probable that

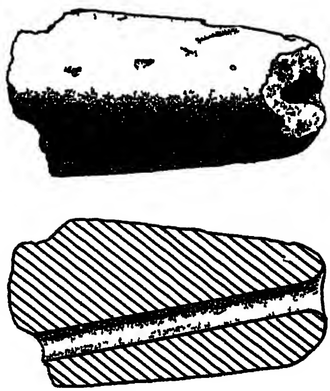


FIG. 59.—Pottery pipestem (?). Arroyo Sarandí. Length, 1½ in. (14/4784.)

[87] Dr. G. C. Vaillant has been kind enough to inform me that his recent stratigraphical studies indicate the appearance of this trait toward the top of the Archaic floors in that locality.

they owe their origin to Querandí contact with Guaraní of the delta islands.

Several minor objects of pottery, in addition to numerous sherds, were encountered on the Sarandí. They include the three clay pendants illustrated in Fig. 58; these are crudely made, but one of them has incised geometric decoration. Another discovery was a broken pottery cylinder with a hole drilled through it (Fig. 59), which may have been a bead or perhaps the stem of a pipe.[88] In Fig. 60 we illustrate a pottery disc with a large hole in the center, which may be a loom-weight. Schmidel, it will be recalled, states that the Querandí wore small cotton aprons and,

FIG. 60.—Pottery disc. Arroyo Sarandí. Diam., 2½ in. (14/4788.)

FIG. 61.—Hammerstone. Arroyo Sarandí. Length, 3 in. (14/4771.)

although they could have grown no cotton themselves, they might easily have obtained it in trade with the tribes to the northwest. The art of weaving was known to the Tehuelche, who made narrow fillets. We have seen loom-weights in the collection of Mr. John Hamilton from as far south as the Galliegos valley.

We have already spoken of pottery fire dogs, or pot rests, at Arroyo Malo. At Arroyo Sarandí we found a different type which was hollow (Fig. 62). No complete examples were recovered, but there were many fragments. Similar pieces found near the Río de las Conchas appear in Fig. 63, and we have seen a fragment found near Lake Chascomús.[89]

[88] Outes (1917b) discusses a pipe from Entre Ríos.
[89] American Museum of Natural History, $\frac{41}{416}$

STONE OBJECTS

Stone objects were not found in great numbers, doubtless owing to the lack of mortuary offerings and to the fact that stone utensils by their very nature do not frequently find their way to refuse-heaps. There was a notable absence of discarded chips, which indicated that manufacturing had not been carried on here.

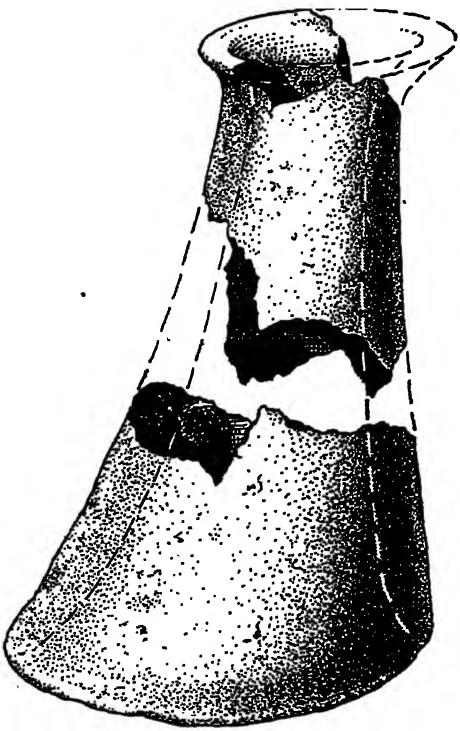


Fig. 62.—Pottery fire-dog. Arroyo Sarandí. Restored height, 7 in. (14/7127.)

Several stone bolas were recovered, some of which are shown in Fig. 64. They exhibit both narrow and broad grooving, forms which have as wide a distribution as the bolas themselves.

A small quartz arrowpoint (Fig. 65) had a triangular blade like one found at El Cerrillo (Fig. 41). No stone spearpoints such as Schmidel describes among the Querandí were encountered.

Hammerstones were found in some numbers. In Fig. 61 we illustrate a stone which has been used both for pounding and for grinding.

It will be recalled that historical accounts of the Querandí speak of their grinding the flesh of dried fish into flour which they mixed with

grease. In Fig. 66 we show a fragment of a mortar which may have served for this purpose. However, we are dealing with post-Conquest remains of a nomadic people forced to settle down where they were exposed to missionary influence, so that it is possible that the inhabitants of Arroyo Sarandí had learned to practise agriculture and that this mortar was used to grind corn.

FIG. 63.—Objects from the Río de las Conchas. (After Oliveira César.)

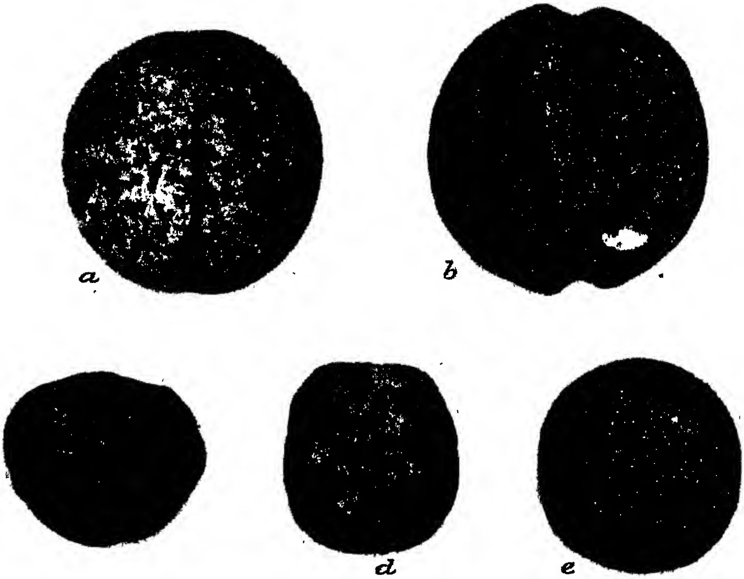


FIG. 64.—Bolas. Arroyo Sarandí. Diams., 1⅞ to 2¾ in. (*a*, *b*, 14/4774; *c*, *e*, 4775; *d*, 4777.)

FIG. 65.—Arrowpoint. Arroyo Sarandí. Length, 1½ in. (14/4782.) (14/4782, 4820.)

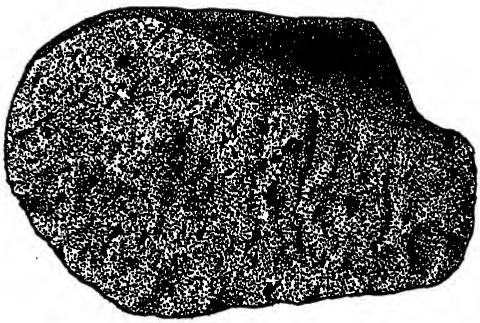


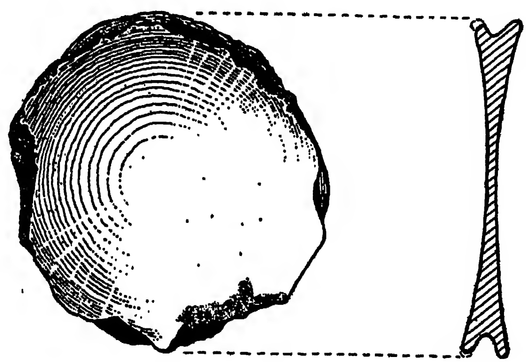
FIG. 66.—Fragment of mortar. Arroyo Sarandí. Length, 2⅞ in. (14/-4769.)

In Fig. 67 we show a grooved disc of purple stone, which was perhaps used as an ear-plug. Lehmann-Nitsche (*108, 112*) has illustrated objects of similar shape and size from Patagonia.

SHELL

During the excavations at Arroyo Malo no shells of any kind were recovered, while at El Cerrillo shells occurred only as refuse. At Arroyo Sarandí, however, we encountered several shell ornaments, seen in Fig. 68, which in no instance were associated with burials. They consist of pierced discs of various sizes, and of a long slab of the same material.

FIG. 67.—Stone disc. Arroyo Sarandí. Diam., 2 in. (14/-4781.)



We imagine that the discs may have been attached to the clothing after the fashion of copper plaques employed by the Charrúa, or possibly they may have served as ear ornaments. Nordenskiöld (*149*) has described shell discs sewn to form a pattern among the Ashluslay but the discs in question are much smaller than any except one of those from Arroyo Sarandí.

We only once found objects definitely associated with a burial at Arroyo Sarandí. This burial was that of a woman and a child—a group very similar to that pictured in Fig. 51, *a*. Around the neck of the woman was a necklace of 209 snail shells. The ends of these had been knocked off, and in some cases they had been neatly trimmed, as shown in Fig. 69, so that it was possible to string them. Nordenskiöld (*149*) has described and pictured snailshell necklaces still used by Indians of the Chaco, such as the Ashluslay and Choroti, but these peoples employed a different method of stringing, for they punctured small holes near the lip of the shell.

BONE AND HORN

We found many objects of bone and horn at Arroyo Sarandí, similar in type, for the greater part, to those we had previously uncovered on the Paraná Guazú. The mainland specimens, however, seem to have been made with a nicer eye for symmetry and with a higher surface polish, although the latter characteristic may be no more than the result of better preservation in the ground.

Bone awls were exceedingly common. Sometimes they are small slender tools such as Fig. 71, *a, b, f, g,* sometimes they are irregular fragments of bone with one end sharpened (Fig. 71, *c, d, e*). Some are

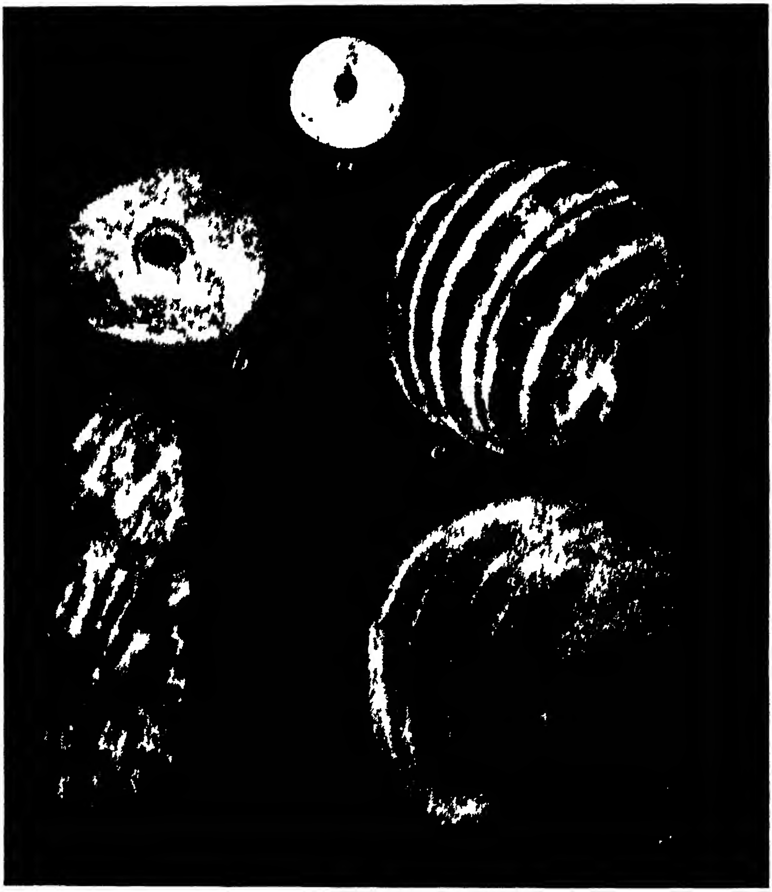


FIG. 68.—Shell ornaments. Arroyo Sarandí. Length of *d*, 2⅞ in. (14/4778, 4779.)

FIG. 69.—Bead from a necklace. Arroyo Sarandí. Length, ⅝ in. (14/4780.)

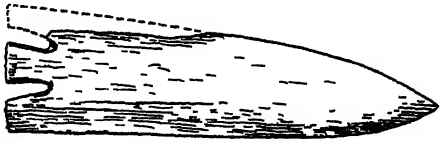


FIG. 70—Bone arrowpoint. Arroyo Sarandí. Length, 2⅝ in. (14/4765.)

made from the longbones of deer with the articulation serving as a handle (Fig. 71, *h*, and Fig. 73, *a*, *b*), and others are made from sharp-pointed fish-spines (Fig. 73, *c*, *d*, *e*). All of these forms were found also at El Cerrillo, as well as large antler punches, such as Fig. 72, *a*, of which we obtained a number at Arroyo Sarandí.

We have already spoken of horn implements from El Cerrillo used to string fish and of their use today in the Chaco. At Arroyo Sarandí we discovered identical specimens which, like those from the Paraná Guazá, sometimes carried simple incised adornment (Pl. XXVI, *a*, *b*, *d*). A

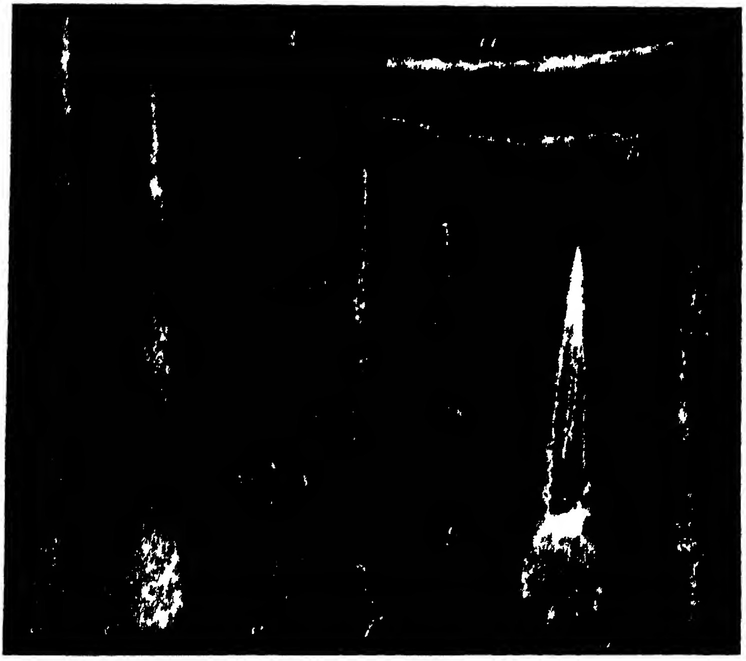


FIG. 71.—Bone implements. Arroyo Sarandí. Lengths, 2 to 4½ in. (*a*, *b*, 14/4656; *c*–*h*, 4757; *i*, 4763.)

second type, however, not only has the oval slit in the side but also two circular holes placed slightly to the rear and a quarter of a turn away (Pl. XXVI, *c, e*). Two specimens which may be variants of the same instrument appear in *f* and *i* of the same plate. Both are of bone, and it is clear that a cord formerly was attached to them, for one has an encircling groove near the base, while a large hole has been drilled through the other.

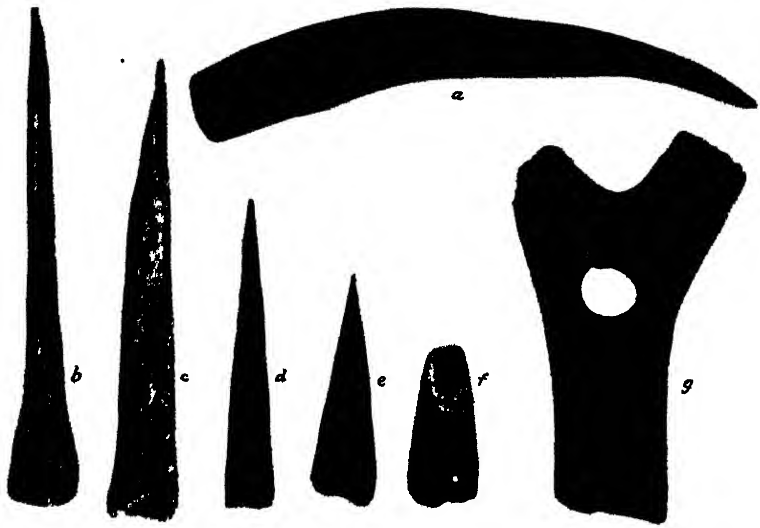


FIG. 72.—Bone and antler implements Arroyo Sarandí. Lengths, *a*, 10⅝ in.; *others*, 1½ to 5½ in. (*a*, 14/4768; *b, c, f*, 4751: *d, e*, 4750; *g*, 4746.)

Weapons were more frequently encountered at Arroyo Sarandí than at El Cerrillo. For the greater part they were lancepoints (Pl. XXVI, *g, h,* and Fig. 72, *b–f*), made from the longbones of deer, with the hollow base serving as a socket. Sometimes there is a small hole in the side, as if for securing the head on the shaft by means of a peg. The points usually are sharp, but some of them have a chisel-like blade. These lanceheads are of proper size and weight to have tipped the darts which Schmidel describes among the Querandí when they attacked the first settlement at Buenos Aires. We found none of the flint spearheads mentioned by him; however, though Outes (*159,* Figs. 16–18) has pictured some which are presumably of Querandí origin.

Two bone pegs for spear–throwers are of interest in connection with the spearheads. One of these we illustrate in Fig. 74, and the other, now in the Museo de La Plata, is of similar form. While there is historical notice of spear–throwers among the Timbú and eastern Chaná, no archeological specimens have come to light.

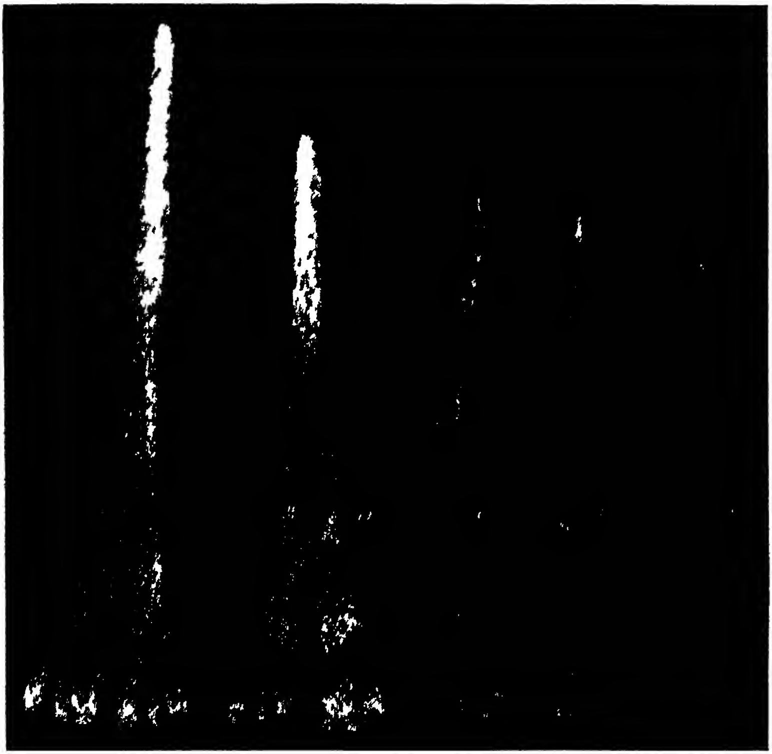


FIG. 73.—Bone and fish-spine awls. Arroyo Sarandí. Lengths, 4 to 6½ in. (*a*, *b*, 14/4767, *c*, *d*, *e*, 14/4752)

The inhabitants of Arroyo Sarandí used three types of arrowpoints. One of these, made of stone, we have already considered (Fig. 65). A second form, seen in Fig. 71, *i*, is made of bone, with a long and narrow tang but no barbs, and is practically identical with points from El Cerrillo (Fig. 47). A third type (Fig. 70) has a thin, symmetrical bone blade, barbs, and tang. It is noteworthy that the barbs are formed not by knocking off the rear corners of the blade, but by sinking slots in the base, for this feature points distinctly to the south and reaches its greatest

intensity in Tierra del Fuego (*123,* Fig. 40). One of the discoveries of Oliveira César on the Río de las Conchas was a flat-bladed bone arrow-point, which we reproduce in Fig. 63, *c*. It differs from our find from Arroyo Sarandí in the arrangement of the barbs and tang, and because it has incised designs on the sides of the blade.

IV.—Arroyo Rodeo

The Arroyo Rodeo is a small stream to the north of the Arroyo Malo. Just before our arrival, a dugout canoe was discovered in its muddy bottom at a point a few yards east of the Canal Arias—which we have located as an archeological site in Fig. 6. The canoe was raised with some difficulty and dragged ashore, where it presented a few weeks later the

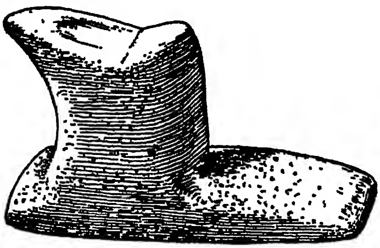


Fig. 74.—Bone spear-thrower peg. Arroyo Sarandí. Length, 2 in. (14/4766.)

Fig. 75.—Clay head. Province of Corrientes. After Torres, 1907.

appearance shown in Fig. 76. Sometime afterward we boxed it and shipped it by barge and truck to the Museo de La Plata as part of its share of the collection obtained.

Before the stern was broken off, this canoe must have been nearly forty feet long, while it is about three feet wide and two feet deep. It has the slender, tapering ends characteristic of Chaco canoes,[90] and in the bow is a hole for mooring it by driving a stake into the shore. Dr. Márquez Miranda has published a fuller description and exact measurements.[91]

GENERAL OBSERVATIONS

We have reviewed the archeological evidence obtained at three sites in the Paraná delta, as well as the available historical accounts of the Indians who once occupied this region. It remains to discuss the more gen-

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[90] Grubb (1914a, p. 84) has illustrated a Lengua canoe of similar type.
[91] Twenty-third Intern. Congr. Amer., New York.

eral problems and interrelations associated with our data, and also to determine the cultural currents to which the Paraná finds pertain.

Cultures of the Paraná Delta

Argentine scholars for some years have recognized three cultures in the Paraná delta, which they define on the following bases:[92]

I.—The first is distinguished by cemeteries containing urn-burials in large jars with either painted or corrugated decorations. Accompanying these are found labrets and stone celts, but no other typical lithic implements. Bone tools have not been classified.

Fig. 76.—Dugout canoe. Arroyo Rodeo.

II.—The second culture is distinguished by pottery with plastic zoömorphic forms set on the rims and by flexed burials in artificial mounds like those of North America. There is little stonework, but many bone tools occur.

III.—The third culture is characterized by pottery vessels of simple form, adorned at times with incised patterns or simple painted bands. Stone industry is crude and exhibits no typical forms, but bone tools are common. Burial is by inhumation in elevated lands.

[92] A bibliography of the literature describing each of these groups has been published by Outes (1923, pp. 17–19, footnotes).

The first of these cultures is attributed to the Guaraní and is typified by such sites as Arroyo Malo. The third is attributed to the Querandí and is typified by such sites as Arroyo Sarandí. The second group must be assigned to the other tribes dwelling on the lower course of the Paraná. We believe that the second and third types form part of one cultural unit.

There can be little doubt that the Guaraní remains have been identified correctly, for they are in accord with the early historical accounts of this people as well as with the handiwork of modern Guaraní tribes such as the Chiriguano. Archeological finds typical of this culture occur on the Alto Paraná and in the delta, though isolated pottery fragments have been discovered near Santa Fe, in Santo Domingo Soriano, and the San Blas peninsula. The following sites may be listed: [93]

Paraná Delta	Martín García island.
	Los Vizcainos island.
	Las Conchas.
	Arroyo Malo.
	Río Paraná Miní.
	Isla Paycarabí.
	Río Carabelas.
	Puerto Landa.
Alto Paraná	Yaguarazapa.
	Tacarú Pucú.
	Puerto Francés.
	Toro Cuá.
	Arroyo San Juan.
	Puerto Unión.
	Arroyo Tatiyupí.
	Colonia Militar del Iguazú.

We agree with Argentine students that their third culture represents the Querandí Indians, but we do not believe that their second type should be regarded as a separate "culture"— provided this word be used in its usual anthropological sense. On the contrary, we regard the two as closely related phases of a single widely spread cultural unit. Let us see what grounds there are for separating or uniting them.

In the first place, contemporary historical records of the delta Indians indicate if not identity at least close similarity between the riverine tribes

[93] This list is taken largely from Outes, 1917a, p. 275; 1918, pp. 170–182; Ambrosetti, 1895. Bibliographic references will be found in Outes' publications.

and the inhabitants of the adjacent plains. This relationship is summarized and may be seen at a glance in Table II (p. 122). This digest of various historical sources is buttressed by definite statements of early writers such as Díaz de Guzmán (*53*, p. 30), who claims that above Buenos Aires there dwelt sundry "Indian nations, and although they have different languages they are of the same quality and customs as the Querandí, mortal enemies of the Spaniards, and whenever they can execute a treasonable act they fail not to do so. Further upstream are others called the Timbú." The evidence of eye-witnesses, then, does not yield ground for belief that the plains and delta tribes enjoyed separate cultures—a conclusion confirmed by the archeological remains, which we shall now discuss.

The proposed second culture has been isolated chiefly because at certain archeological sites in the delta modeled heads (Fig. 75) occur on the rims of pottery bowls.

In defining this "culture" various writers have discussed the heads in detail, but have said little about incised adornment associated with the heads, which is without question very similar to that which we encountered at El Cerrillo. Neither Dr. Torres nor the writer, indeed, found such heads at El Cerrillo, but Dr. Torres encountered one near-by on the Río Carabelas (*225*, Fig. 16), where the other ceramic remains evidently are closely related to El Cerrillo. On this basis, then, we are justified in regarding both sites as belonging to one culture.

Modeled clay heads are not common in the delta, but they increase in number as one proceeds up the Paraná, and quite a few have been found in the vicinity of Santa Fe. At no site yet examined, however, have they occurred in sufficient quantity to serve, in the opinion of the writer, as a proper criterion of culture. On the contrary, their distribution and relative quantity indicate that they are a non-typical and intrusive element of northern origin.

Examination of any large museum collection will reveal very similar clay heads (similarly placed on bowl rims) from the Chaco, the Amazon valley, Venezuela, the Greater and Lesser Antilles, and southeastern United States. For the greater part, such heads have reached museums unaccompanied by adequate chronological data, but in some instances they are known to be of fairly recent date. As yet information is lacking to warrant any general conclusion, except that usually they are the product of Arawak tribes or of peoples in contact with Arawak culture.

Arawak peoples and Arawak culture in the Chaco had penetrated by the sixteenth century as far as latitude 21° S, where the Guaná tribe lived

between the Paraguay and Alto Paraná rivers. Their Guaycurú neighbors to the south and west were related culturally, physically, and linguistically to the inhabitants of the Paraná delta. The Mbayá tribe held the Guaná in a condition of semi-slavery, and forced them to cultivate their lands, for the Mbayá themselves did not understand the art of agriculture. This contact explains the presence of Arawak traits in the culture of Guaycurú tribes, such as the Mbayá. But in addition it is recorded that the Guaná used to descend the Paraná as far as Buenos Aires, where parties of fifty or one hundred would hire themselves out as laborers (*181*, pp. 156–157). Here is evidence of Arawak penetration to the Paraná delta at least in colonial and republican times; and a possible explanation of Arawak influence in that locality is that this contact was established before the coming of the Spaniards. Thus the modeled clay heads we have discussed may be accounted for without isolating them as a separate local culture.

Another distinction which has been made between the plains and the delta cultures is that the former includes many more objects of stone. Yet it is obvious that Indians of the mainland possessed readily available supplies of this material, but the inhabitants of riverine mud-flats could obtain stone only by commerce or by a long journey to the territory of hostile tribes. The typology of stone artifacts therefore seems a surer guide to cultural relationship than the relative frequency of their occurrence.

Argentine scholars also regard plains and delta remains as separate cultures because flexed burials in artificial mounds have been discovered throughout the delta. Our excavations, however, showed that burials at full-length were also present in the delta, while flexed burial was sometimes employed by the Querandí of the plains. Dr. Torres regards the El Cerrillo mound as partly artificial, but we could find no evidence to support this, for the numerous ash pockets (Fig. 30) and the general distribution of rubbish indicated that the living surface had been gradually elevated as the result of occupancy.

Such, then, are some reasons for rejecting the hypothesis that plains and delta remains represent separate cultures. We shall now examine archeological evidence indicating their fundamental unity.

We have already shown that the El Cerrillo finds correspond to the second or riverine cultural group proposed by Argentine scholars, except that no example of the relatively rare modeled heads were found, while the Arroyo Sarandí specimens may be attributed to the plainsmen Querandí. A comparison of the discoveries at these two sites discloses that rather similar incised pottery comes from both; bone awls, needles,

spearpoints and arrowpoints are practically identical; fish-spine awls, antler punches, antler arrowshaft straighteners and fish-stringers are present in each; similar types of bolas and stone arrowheads were found; and in addition, as we have shown, all first-hand historical notices of the Indians scarcely distinguish between the Querandí and delta tribes, except, of course, the Guaraní. Here is positive proof of a very close affiliation of culture, clearly brought out by our illustrations [93a] and confirmed by the summary of cultural traits listed in Table II (p. 122).

Pottery and its decoration, as is generally agreed, furnish the surest single critical index for determining the status and relationship of material culture, so it may be well to compare in detail the finds at El Cerillo and Arroyo Sarandí. Both sites characteristically produce rather small, well-fired vessels of globular or subglobular shapes, with unrestricted orifices, adorned with identical or very similar incised designs. This pottery is frequently so much alike that even after careful study it is not always possible by eye alone to distinguish specimens of one locality from those of the other. There are, however, certain local features which are distinct, such as the occasional presence of painted ware, slips, and color-separation by incising at Arroyo Sarandí, but these features are not common, and they are found in Querandí pottery only where that people were in immediate contact with the Guaraní. Every culture-unit in the New World includes similar variations.

To give a general view of Argentine incised pottery we have assembled in Pl. XXVII patterns typical of various localities from southern Patagonia to the Chaco, a distance of about 1700 miles. A glance at this illustration is enough to establish the unity of pottery decoration throughout this great territory, and this unity extends to other phases of culture—as is attested by archeology and history. Hence it is clear that from Tierra

[93a] The similarity between the two sites is established by comparison of the following illustrations:

	El Cerrillo	*Arroyo Sarandí*
Pottery shapes	Fig. 32	Figs. 52, 53a
Pottery decoration	Pl. XIV, Fig. 38	Pls. XXIII, XXV
Bone awls	Pl. XX	Fig. 71
Bone needles	Fig. 43	Fig. 71
Bone spearpoints	Fig. 44, Fig. 45	Fig. 72, *f*; Pl. XXVI
Bone arrowpoints	Fig. 47	Fig. 71, *i*
Bone fish-stringers	Pl. XXI	Pl. XXVI
Fish-spine awls	Fig. 42	Fig. 73
Arrowshaft straighteners	Fig. 48	Fig. 72, *g*
Designs on bone	Pl. XXII	Pl. XXVI
Stone arrowpoints	Fig. 41	Fig. 65
Bolas	Fig. 40	Fig. 64

del Fuego to Paraguay the migratory tribes of the plains have shared a common basic culture, for which Father Cooper [94] has suggested the name Campestrian. This agglomeration of tribes may be compared to the Sioux and their neighbors on the prairies of North America, who shared basic traits, but differed from tribe to tribe by reason of local modifications and developments, as well as by the adoption of foreign practices such as agriculture.

Fundamental features of Campestrian culture, without reference to the effects of European contact, may be set down as follows:

1.—Portable windbreaks for houses, made of skins in the south and of mats in the north.
2.—Fur mantles painted on the skin side.
3.—An apron in place of a breechclout.
4.—Woven fillets or headbands.
5.—Lip–plugs, large ear–plugs, and shell necklaces.
6.—Tattooing and facial painting.
7.—Incised pottery and wooden bowls.
8.—Bow and arrow, but no quiver.
9.—Patriarchal family life, marked by little respect for authority except in war, and by extreme individualism.
10.—Nomadic, non–agricultural mode of life.
11.—Polygyny and divorce recognized, but uncommon except for chiefs.
12.—Elaborate initiation ceremonies for both sexes.
13.—Rigorous treatment of boys during such ceremonies, usually including scarification.
14.—Dances, but usually without dance masks.
15.—Little community religious ritual.
16.—Disease extracted from the body by massage and suction.
17.—Secondary burial with offerings to the spirit.

It is obvious that no one tribe in so vast a territory will have all these characteristics and, at the same time, that there will exist both tribal and regional variations. Thus we find agriculture, canoes, and spear–throwers among the inhabitants of the lower Paraná. Finger mutilation on the death of a relative appears on both sides of the R. La Plata. Head trophies were sought in this region and in the Chaco. To the south in Tierra del Fuego the Ona and Haush had no pottery or weaving, but employed dance masks. On such a basis, Campestrian culture may be

[94] In XXI Inter. Congr. Amer., pp. 417-418.

split into subgroups, marked by regional differences, although clearly conforming to the group as a whole.

Cultural Limits and Extensions

The distribution of technological and cultural traits has assumed great importance to the anthropological world in recent years, because through it students have attempted to work out the course of cultural development and of ethnic dispersion—some for a hemisphere, others for the entire world. The validity of these hypotheses does not concern us at the moment, but as the lower Paraná embraces an area of cultural change—the southern extension of tropical, cannibalistic, agricultural peoples—it seems well to name and to delimit the critical alterations in material culture, both in the vicinity and among neighboring tribes.

HOUSES

The Guaraní group in the Paraná delta built thatched houses in fixed localities, and their Timbú neighbors employed similar dwellings—the southern outpost of permanent habitations in eastern South America. Other tribes in the vicinity had no real houses but employed portable windbreaks made of mats or of skins—a form of shelter typical of the Campestrian culture. As for the materials employed, it is obvious that mats would be less wind- and water-proof, but would be much more convenient to transport on account of their lightness. In the La Plata district mats were employed by the Querandí, Charrúa, and Yaró tribes. Nordenskiöld (*149,* pp. 23–24) lists mat shelters among the Lengua, Toba, Mbayá, and Abipones, while Del Techo (*219,* pp. 650, 653, 741) speaks of their use by the Frentones and the Guaycurú, and in southern Tucuman. Palavicini adds the Carajá, Payagua, Machicuy, Chamacoco and Araucanians (Pehuenche) (*182*).

Skin shelters have received historical notice among the Querandí, Charrúa, and Minuané. The Tehuelche and Huarpe employed them in the sixteenth century (*180,* Lib. XX, cap. V and illustration; *195,* II, 97–98), though with the advent of horse transportation they set up larger skin dwellings with a roof and three (or sometimes four) walls supported on poles (*145,* pp. 67–68). In Tierra del Fuego the Ona and Haush tribes made use of skin wind-breaks (*123,* pp. 59–62, 107), but the Yahgan domed huts, though sometimes covered with seal-hide, appear to have another origin, for they are found on the west coast to the north as far as Peru among the Alacaluf, Chono, and Chango tribes.

DECORATION OF THE BODY

Facial and body painting were characteristic of all Campestrian tribes from the Chaco to Beagle channel. Literary sources, however, do not always distinguish tattooing from painting, so that one hesitates to assert the absence of the former simply from lack of positive evidence. Wounds or burns commonly were inflicted during the period of initiation, and it was a simple matter to rub in pigment at that time. In the delta region, tattooing is definitely ascribed to the Charrúa and Minuané. Nordenskiöld (*149*, p. 120, map 19) and Schmidt (*203*) have commented on the general distribution of this custom throughout South America.

Large ear-plugs, according to Nordenskiöld (*149*, p. 117, map 18; *148*, tafel 14, abb. 30), were worn by such Chaco tribes as the Choroti, Ashluslay, Mataco, and Toba, also by the Gês peoples, and by the inhabitants of Peru. We may add on historical grounds several tribes of the R. La Plata and Paraná delta, including the Yaró, Chaná, Chaná-Timbú, Mbeguá, and Timbú, while archeological finds indicate their use by Tehuelche (*108*, *112*) and Querandí.[95]

Nasal decoration among South American Indians falls into three classes: nose sticks (which pierce the septum), nose pendants (which hang from the septum), and nose-plugs (which are inserted in the wings of the nose). The last type is characteristic of the area under discussion and is attributed to the Charrúa, Chaná, Mbeguá, Chaná-Timbú, Timbú, Corondá, and Quiloaza.

Labrets seem to have been common in the delta and are reported among the Querandí, Charrúa, Yaró, Chaná, Chaná-Timbú, Mbeguá, Timbú, and Guaraní. This ornament has a wide distribution throughout both North and South America (*150*, pp. 71-77).

WEAPONS

All the tribes of the lower Paraná and La Plata were archers. It is said of Timbú arrows that they were short and three-plumed, like those of the Tehuelche—a statement implying that their bows were small and stiff like those of Patagonia.[96] We know nothing of their methods of archery. Both to the north and south, however, among the Ona of Tierra del Fuego (*123*, Fig. 34) and such Chaco tribes as the Ashluslay (*148*, abb. 67), the bow is held diagonally with the index finger extended along the path of the arrow.

[95] See our Fig. 67.

[96] "Arcos cortos y reclos y anchos de madera muy fuerte, y flechas como las que usan los turcos y con cada tres plumas."—Oviedo, Lib. XX, cap. vi.

There is no mention of a quiver among the delta tribes with the exception of an Indian near Santa Fe, who is said by Barco de Centenera and Lozano to have carried one. Of the Yaró and Chaná–Mbeguá it is definitely stated that they carried their arrows in their hands, and this we believe was the general practice.[97] It will be recalled that the Tehuelche and the Puelche of the Cordilleras also had no quivers, but inserted their arrows in their headbands so that the plumed shafts protruded like a crown. Nordenskiöld (*151*, p. 49) writes that none of the tribes he encountered in northeastern Bolivia and the adjacent portions of Peru and Brazil carried quivers.

The use of light darts was common among the delta tribes, and the Querandí, Chaná, and Timbú are known to have employed spear–throwers, a fact which marks their southern limit in eastern South America. After coming in contact with Europeans the plains tribes took to large heavy spears. While these were primarily associated with horse culture, in some cases they were adopted before the use of the horse, for Schmidel writes that the Timbú in his day employed them.

Bolas were first noted by Europeans among the Querandí and Charrúa. Outes (*164*a, pp. 427 et seq.) has traced the gradual spread of this weapon southward to the Puelche, among whom it was first noted in 1599, and to Patagonia, where it appeared in 1766. It was seen on the north coast of Tierra del Fuego between 1829 and 1832 (*62*, p. 186, footnote), and its use spread among the Ona as far south as the Río Fuego (*123*, Fig. 41), though it never became common in that island.

When we look northward and westward from the R. La Plata, however, the spread and even the distribution of bolas does not present a clear picture. In a small and crude form, sometimes of stone, sometimes of copper, they appear to have been employed in prehistoric times throughout the Argentine provinces of Córdoba and Mendoza, where today they are called by the Indian name *libes* (*105*, p. 6). Across the Andes among the Araucanians in Chile they are known as *laque*, and again their use may have been prehistoric (*105*, p. 16). We have dug up bolas, together with Diaguita pottery, on the Punta de Teatinos near Coquimbo in Chile. In the Chaco, where there is no stone, wooden bolas are used as toys among such tribes as the Choroti, Ashluslay (*149*, p. 45), Mojo, Mataco, Abipones, and others, as well as by the present Aymara and Quichua

[97] The fact that the quivers are not typical of Campestrian culture makes it improbable that the Ona and the Haush employed them when they first reached Tierra del Fuego. Doubtless these tribes acquired the use of the quiver from the Yahgan, or Alacaluf, which is indicated not only by the distribution of the quiver but also by the material, which was seal-hide, not commonly employed by the Ona for any other purpose.

Indians in Bolivia (*66*, p. 34). Could we limit the distribution to the peoples we have mentioned, it would appear that the bolas originated on the plains near the R. La Plata and spread thence to the north and south. However, grooved hemispherical stones of similar type are found archeologically in southern Brazil and in Bolivia, Ecuador, the Antilles, Central America, Mexico, and the United States—regions where bolas probably never were used.

Rivet (*194*, pp. 229 et seq.), who has studied this distribution in a most scholarly fashion, comes to the only possible conclusion in regard to it: namely, that grooved spherical stones served for different purposes in various places at various times; and he notes their use as bolas in the south, as sling-stones on the Pacific coast of South America, as clubs in Mexico, as sinkers for fishnets, hammers, etc., in the United States. The same authority points out that the Cañaris of Ecuador used bolas in historical times, which, perhaps, is the northern limit of this weapon in South America.

FINGER MUTILATION

The amputation of a finger-joint as a sign of mourning took place among the Charrúa, Minuané, Yaró, Timbú, and probably the Querandí.

This painful custom is of world-wide distribution. In South America, in addition to the R. La Plata district, it is recorded among Chaco tribes and the Yaros of Chile (*99*, pp. 114–116, 277). The Maya practised it during the period of the Old Empire.[98] Among the Aztec it was not the living but the dead who were mutilated, for it is recorded that the middle-finger joints of the left hand of women who died in childbirth were prized as charms and were stolen unless the grave was guarded.[99] In North America,[100] finger mutilation has been reported among the Iroquois; plains tribes, including the Mandan, Dakota, Crow, and Cree; various Californian groups and also northwestern tribes, such as the Tlingit Tsimshian and Haida. In addition this custom was known to Aurignacian man in Europe, to Bushmen Hottentots and Pigmies, to Tonga and Fiji, to the natives of Australia, to the Nacobar islands and New Guinea, and to the Dravidians of Mysore in southern India.

This world-wide distribution and great antiquity, as indicated by the practice of finger mutilation in Aurignacian Europe, might be thought to

[98] Mr. and Mrs. O. G. Ricketson described to me an infant urn-burial with an adult phalanx discovered at Uaxactun.

[99] T. A. Joyce, Mexican Archæology. London. 1914. p. 100.

[100] Solas, Ancient Hunters. London. 1915. pp. 349 et seq.

indicate the dissemination of the custom from a single source. It should be recalled, however, that the purpose of the operation indicates at least four sources. Thus among American tribes in general it was a sign of mourning, in Mexico as in mediæval Europe it was associated with witchcraft, in Polynesia it pertained to sickness, while in India it formed part of the birth ceremony.

HEAD TROPHY

The scalp or the complete head of a slain enemy was preserved among the Querandí, Charrúa, Yaró, and probably the Minuané—a custom pointing to the north and west, the general distribution of which has been studied by Friederici (*65*) and Nordenskiöld (*149*, p. 184).

AGRICULTURE

Historical sources attribute the art of agriculture to the Guaraní, Mbeguá, Timbú, and Chaná–Timbú. Our investigations at El Cerrillo on the Paraná Guazú indicate that the Chaná–Mbeguá, who probably lived there, used vegetal but not necessarily agricultural food. It is definitely stated that all tribes living on the mainland beside the delta were non–agricultural: Querandí, Charrúa, Minuané, Yaró, Chaná, and others. In fact, it seems safe to conclude that with the exception of a few relatively small tribes the southern boundary of agriculture in the eastern half of the continent before European contact coincided with the southern limits of the Guaraní tongue. Missionary influence has of course extended agriculture far toward the south among formerly non–agricultural tribes, as, for instance, the Yahgan on Navarín island, who cultivate small vegetable gardens.

The historical sources on which this distribution is based have already been discussed and in the main are reprinted in Appendix I, so that it is unnecessary to go over them again. They form the most trustworthy base for delimiting agriculture, but several recently published maps are not in agreement. For instance, a distributional map before me attributes maize and even manioc culture to the Charrúa, who, numerous authorities assert, had no cultivation before the advent of the Spaniards and never acquired this art. Another distributional map, which has been reprinted several times in recent years, shows agriculture among the Charrúa and even the Querandí.

The plants grown in the Paraná delta by the natives were limited to three varieties: maize, beans, and "calabashes." There is some uncertainty

as to the last of these because the Spanish equivalent is used at times to mean calabash and at times to mean squash.

INTOXICATING DRINKS

It is generally assumed that the knowledge of fermentation is confined to agricultural tribes, but this does not hold true in the region under discussion, for the Charrúa had learned to make wine from honey and water. We have no evidence, however, that this custom was pre-Spanish.

TEXTILES

The art of weaving was known apparently to all the tribes of the Paraná and to those to the south as far as the Straits of Magellan. Tehuelche woven fillets have been described by Musters, those of the Araucanians by Brother Claude Joseph, Kermes, and Looser, while Schmidel speaks of woven aprons among the Charrúa, Querandí, and Timbú. We have no direct information in regard to the other peoples of the delta, but it seems reasonable to assume that they likewise practised this art. In fact, the principal tribes in South America without weaving at the time of the Conquest were certain tropical peoples who wore no clothes or else made bark cloth, primitive fishing tribes of the west coast, and the inhabitants of the Magellanic archipelago, who clad themselves in skin robes. It is noteworthy, however, that the nomadic tribes south of the Chaco used textiles not so much for protection as for adornment, which is quite natural, for they could have acquired cotton or llama wool only in small quantities by trade, and they did not have facilities for shearing the llama, guanaco, or dog.

BASKETRY

The humidity of the soil throughout the delta of the Paraná had destroyed most perishable objects, but from an historical source it is known that the Querandí made baskets, which are said to have held water—possibly as the result of close weaving, or perhaps as a result of waterproofing. We have seen no mention of baskets among the Tehuelche, but the Araucanian tribes, like all the inhabitants of the Pacific coast of South America, made excellent coiled basketry, and the Mapuche group, who seem to have migrated to Chile from the Argentine Pampas about 1300 A.D., made water-tight baskets, as did the Huarpe of Mendoza and San Juan.

POTTERY

To define the limits of pottery with accuracy it is necessary to distinguish between fabrication and transportation. The fabrication of

TABLE VII

Pottery Traits	Southern Limit	S. Lat.	Authority
Pottery manufacture	South bank of Deseado river	48°	Outes, 1904
Incised designs	South bank of Deseado river	48°	Outes, 1904
Stippled designs	South bank of Deseado river	48°	Outes, 1904
Handles	Río Chabut	43° 30′	Outes and Bruch, 1910
Stipple-filled designs	San Blas peninsula	41°	Hrdlička, 1912. Torres, 1922
Color separation by incising	Arroyo Sarandí	34° 30′	Thea Heye–La Plata expedition
Monochrome painted patterns	Arroyo Sarandí	34° 30′	Thea Heye–La Plata expedition
Spouts	Arroyo Sarandí	34° 30′	Thea Heye–La Plata expedition
Polychrome painted patterns	Arroyo Malo	34° 30′	Thea Heye–La Plata expedition
Corrugated pottery	Arroyo Malo	34° 30′	Thea Heye–La Plata expedition
Relief modeling	Arroyo Malo	34° 30′	Thea Heye–La Plata expedition
Lugs	El Cerrillo	34°	Thea Heye–La Plata expedition

Southern Limits of Pottery Distribution in Eastern South America.

pottery vessels, as now known, extends south of the Deseado river,[101] or to about south latitude 48°, which also marks the southern limit of incised decoration. We have seen sherds, however, from the Río Gallicgos in south latitude 51° 30′, and believe that the southern limit of transported vessels probably falls at the Straits of Magellan, or approximately a degree farther south. The point is perhaps not of great importance if we know the location of the manufacturing boundary. Corrugated vessels, characteristic of Guaraní culture, were made as far south as the Paraná delta and Martín García island. A sherd which must be the result of transportation has been reported from the San Blas peninsula. Polychrome pottery also extends to the delta and to Martín García island, but monochrome painted designs occur on the south bank of the Luján river. We do not believe that this type of decoration was characteristic of the Querandí as a whole, but only of those who had come in contact with the Guaraní. The southern boundary of various technical pottery traits is listed in the accompanying table.

Chronology

The age of various skeletal remains and artifacts from the Province of Buenos Aires has been the subject of a long and at times acrid controversy.[102] Although it seems that extreme claims of a geological character must be abated, nevertheless certain finds may be regarded as of considerable antiquity. In the Paraná delta, however, no indication of an early occupancy has yet come to light. Two of the sites we excavated were definitely placed in the colonial period by the discovery of Spanish objects intermingled with aboriginal products, while the third locality yielded artifacts so like those known to be post-Spanish that a wide separation in time seems impossible. No archeological remains of sufficient depth to permit stratigraphical studies or of a kind to indicate the need for them are now known. In short, all available evidence shows that the newly formed lands at the mouth of the Paraná had been occupied for only a brief time before the arrival of European explorers.

[101] Outes, 1904. We judge this from the quantity found.
[102] This subject has been thoroughly review by Hrdlička, 1912.

APPENDIX I

Historical Sources

In preparing descriptions of tribes inhabiting the R. La Plata littoral and the Paraná delta, we found that much of the literature could be obtained in the United States only with the greatest difficulty. In perusing such historical sources as were available, it became evident that many contradictions existed, thus giving ground to different interpretations. It has therefore seemed wise to include in this work certain selections from the chroniclers. We quote some general statements and also the most important and least accessible information about each tribe, arranging the authors in chronological sequence and placing the tribes in the same order as in our Introduction.

GENERAL SOURCES

"La primera generación á la entrada del rio á la banda del Norte se llama los Charruases; éstos comen pescado é cosas de caza, é no tienen otro mantenimiento ninguno. Habitan en las islas otra generación que se llama los Guaranies; estos comen carne humana, como arriba digo; tienen é matan mucho pescado é abaties [maize], é siembran é cogen abatis é calabazas. Hay otra generación andando el rio arriba que se llamán los chanaes é otros questan cabe ellos. Que se llaman chanaes atembures; estos todos comen abaties é carne y pescado. E de la otra parte del rio está otra generación, que se llaman los Carcaraes, é más atrás dellos está otra generación muy grande, que se llama los Carandíes, é otros más adelante hay otros que se llaman los atambúes; todas estas generaciones son amigos é están juntos é hácense buena compañia, é éstos comen abati é carne é pescado. E luego más adentro de la banda del Norte hay otra generción que se llama Mecontaes, que comen pescado é carne; é hay otra más adelante, que se llama Mepenes, que come carne é pescado é algund arroz é otras. . . . E más adelante hay otra generación que se llama Coñame: comen carne é pescado; é otra generación que está cabe estos . . . rios arriba del Paraguay, que se llama los Agaces, y estos comen pescado y carne; é luego más adelante está otra generación de Chandules, que comen abati, carne é pescado é otras vituallas que tienen—Diego García, apud Medina, 1908.

"En la comarca de la dicha forteleza [Sancti Spiritus] ay otras naciones las cuales son: Carcarais y Chanaes y Beguas y Chanaes–timbus y Timbus con (roto) diferentes lenguajes . . . es jente muy bien dispuesta: tienen todos, oradadas las narices ansi onbres como mujeres por tres partes y las orejas: los onbres oradan los labios por la parte baja: de estos los Carcarais y Timbus siembran abati y calabazas y habas; y todas las otras naciones no siembran, y su mantenimiento es carne y pescado."—Ramírez, in Madero, 1892.

"Tres leguas el río arriba está otro río que se llama de Lujan, no muy ancho, pero bien hondable. Siete leguas más arriba se llega á otro estrecho que se llama de los *Quirandies*, y cinco leguas más arriba otro estero que se llama de los *Chanaes–Timbues*.

"Catorce leguas más adelante se llega al río llamado *Carzarana*, donde poblo Gaboto la forteleza de Santi–Spiritus, que despues se despobló, que esta ochenta leguas de la mar.

"Siete leguas de Carçarana, está una laguna ó estero que se llama de los *Quíloaces*, que otros dicen *río de Timbues* ó de *Janaes*, que arriba se dijo *Chanaes*."—López de Velasco, 1894, pp. 560–61.

"En la costa que sigo agora, entra el rio llamado *Guirandies*, desde el cual . . . veynte leguas mas adelante está un rio que se llama *Cacaraña*, é otra diez leguas adelante está otra que se diçe *Timbuz*, é otra diez adelante está otro que se diçe de *Carcaraes;* é otra diez leguas adelante está otra que se diçe *Janaes*."—Oviedo, Lib. XXIII, cap. II.

"Mahomas, Epuaes, y Galchines,
Timbues, Cherandies, y Beguaes,
Agazes, y Nogoes, y Sanasines,
Maures, Tecos, Sansones, Mogoznaes.
El Paranna abaxo, y a los fines
Habitan los malditos Charusaes,
Naues, y Mepenes, Chiloaças,
A pesca todos dados y a las caças."

—Barco Centenera, canto I.

"La gente aqui baxa es en gran suma,
Chiloaças, Beguaes, Cherandies,
Vienen creciendo siempre como espuma,
La flor de todos son los Guaranies,
Mil galas y lindezas de bel pluma
Encima traen de si, mas no confies
En gala, gentileza, y hermosura,
Que la verdura fresca poco dura.

"Al puerto y fuerte llegan bozeando,
Con trompas, y bozinas, y atambores. . . ."

—Barco Centenera, Canto XXIV.

"Síguese á este rio [de Reyes] el Quiloaza, junto al cual, sobre la misma márgen del Paraná, fundó el año de 1573 el capitan Juan de Garay, con gente venida del Paraguay [p. 136] la ciudad de Santa Fé de la Vera Cruz, donde encomendó veinte mil indios de las naciones quiloasas, mepenés, colastinés y tinbúes, de que no han quedado otras reliquias que los nombres y el campo *ubi Troia fuit*. Por la costa arriba vivian los calchaquíes y abipones . . . trasladaron[103] la ciudad á otro sitio, doce leguas de distancia sobre el rio Salado.

". . . [p. 137] Veinte leguas antes de Santa–Fé, (el río Salado) bañaba á un pueblo de indios cristianos de la nacion de *cayastas*, pero ni un indio hay de aquella jente, ni de su nombre hay memoria, sino por el lugar de su situacion.

". . . [p. 138] En Tierra firme, frontera de dicha isla, hubo á tres, cinco y siete leguas de la cuidad [Santa Fe], tres reducciones muy numerosas de indios, *mecoretás, calchines y colastinés*, y siete leguas adelante, otra de *timbúes* que tenia ocho mil almas, y hoy no se halla señal de que haya habido indios en esos parajes.

[103] The original site of the city is now called Cayastá. It was changed to the present location in 1660.

". . . [p. 139] Sobre el cabo septentrional de este rio [Carcarañal ó Tercero], fundó Sebastian Gaboto la segunda forteleza que tuvieron los españoles en todas estas provincias, año de 1528, y la llamaron Sanctí Spiritu : fué célebre este sitio por esta razon y por el fin lastimoso que aquí tuvieron los españoles, muriendo á manos de los bárbaros timbúes que poblaron esta costa desde Gaboto al salado. Hasta ahora, permanecen vestigios de dicha forteleza y el nombre de Gaboto á aquel sitio. En el otro cabo austral del Carcarañal, enfrente de Gaboto; doctrinaban los religiosos fransiscanos una reduccion muy numerosa de los indios chanás, pero en el dia de hoy solo ha quedado tal cual paredon que señala su antiguo sítio, sin permanecer indio alguno.

"Tiene por aquí el Paraná dilatadas y amenísimas islas, pobladas de hermosas arboledas, como tambien lo estuvieron de muchos guaraníes antiguamente [p. 140], pero hoy están totalmente desiertas. . . . Tres arroyos grandes se siguen, llamados los dos como suenan, y el tercero de las *hermanas*. . . . De aqui, dista pocas leguas, el sitio de Buena Esperanza donde el año de 1536 fundó la forteleza de Corpus Christí el capitan Fransisco de Albarado. Entra luego el rio que llaman de los Arrecifes. . . . Cerca de este rio en la costa del Paraná, está un pueblo de indios llamado el Baradero, fundado por el venerable padre fray Luis Bolaños de las naciones Guarani, Albeguay, y Chaná que allí juntó con increibles fatigas; pero encargándose su enseñanza á los clérigos, el número grande de sus feligreses se ha disminuido de tal manera que hoy solo se cuentan algunas familias.

"Peor fortuna corrió la reduccion de los indios cayganés, que antiguamente fué muy numerosa, situatada junto al mismo Rio de los Arrecifes; pero ha mas de 50 años que ni rastros habian quedado de tal pueblo (situado sobre las riberas del Rio de Areco) y hoy solo en los archivos hay memoria de [p. 141] él. Lo mismo sucedió al muy grande pueblo de los indios *baguales*, situado sobre las riberas del Rio de Areco, que es otro que desemboca en el Paraná á 16 leguas de el Arrecife. . . .

"A ocho leguas de Areco, se encuentra el Rio de Lujan . . . entre este rio y el de las Conchas, que dista 6 leguas . . . [p. 142] estuvo situada la reduccion de los *guacunambis*, que eran seiscientas familias, pero ni aun el sitio de su poblacion se supiera si no hubiera habido curioso que mas ha de 50 años hubiese anotado su asolacion.

"A 6 leguas de rio de las Conchas, sobre una punta que llamaron Gorda . . . está fundada la muy noble y muy leal cuidad de Santa María, puerto de la Santísima Trinidad de Buenos Aires. . ."—Lozano, Vol. I, pp. 135–142.

GUARANÍ

"Aqui con nosotros esta otra jeneración que son nuestros amigos los cuales se llaman guaraníes y por otro nombre chandris Estos andan de llamados por esta tierra y por otras muchas como cosarios á cabsa de ser enemigos de todas estotras naçiones y de otras muchas que adelante dire. Son jente muy traidora todo lo que azen es con traycion. Estos señorean gran parte de esta yndia y confinan con los que abitan en la sierra. Estos traen mucho metal de oro y plata en muchas planchas y orejeras y en achas con que cortan la montaña' para sembrar. Estos comen carne umana."—Carta de Luis Ramírez, in Outes, 1897.

". . . del un Rio [La Plata] al otro [Carcarañá] ay sesenta leguas en las quales no vio persona de quien tomase lengua de ninguna cosa eceto á doze leguas deste cabo del dicho Rio de caracaraña que fallo un mayoral dela nacion de los chandules que le salio a rescebir de pas el cual le presento una cofia con cierta chaperia de oro e cobre e cierta plata baxa la qual se quito dela cabeça para darsela."—Declaración de Sebastián Caboto, fide Outes, 1897, p. 182.

"Dentro del La Plata ay gran numero de yslas grandes y pequeñas todas las mas despobladas por ser baxas, y cada año cubre las el Rio de las avenidas que trae, aunque los veranos algunas de estas yslas se habitan por causa de las sementeras que en ellas tienen los Yndios y muchas pesquerias de muy grandes y buenas, son todas de mucha arboleda, aunque los arboles de poco provecho, porque si no son para el fuego y para choças, que los Yndios hazen, para otra cosa no son. . . . pescanse al rrededor dellas muchos y diversos pescados . . . los quales guardan los Yndios para el Ynvierno sin los salar, porque no alcançan sal, sino con abrirlos por medio, a la larga y poniendolos al sol hasta que estan muy secos, y cuelganlos en sus casas despues al humo donde se tornan a curtir mas, y desta manera los tienen de un año para otro, y lo mismo hazen de la carne. Tienen mucho Maiz, no se dan en las yslas ni continente Jucas ni ajos ni Batatas por ser la tierra fria . . ."—Alonso de Santa Cruz, 1908, pp. 55–56.

"Testigo.—El capitán Diego García . . . trujo tres indios, que son los del Río de Solís, que son libres, que son de la géneración de los Atambures, . . . questos tres indios los compraron en el dicho Río de Solís por esclavos de otros indios enemigos suyos, que son los guaraníes, que los comen, é que este testigo, como capitán, los hizo libres á estos tres indios, y el que este testigo tiene, lo tiene para lengua para volver á la dicha tierra . . ."—*Informacion llevantada*, in Medina, 1908, Vol. II, p. 178.

"En el parage de esta [gente que se diçe *chanastinbus*] hay otra gente que se diçen *guaranics*, á la banda del Sur, que son caribes y comen carne humana, y haçen guerra á todas las otras nasçiones del rio, y son muy belicosos y flecheros, y su lengua muy diferente é apartada de las otras."—Oviedo, Lib. XXIII, Cap. XII.

". . . tienen buenas canoas y las palas con remos luengos de á quinçe ó veynte palmos."—Oviedo, *ibid.*

"Entramos por un braço, no calando
Los remos, que las yervas van tocando.

"Salieron a nosotros embixados
Catorze o quinze Indios diligentes,
Con arcos y con flechas denodados,
Mostrandose gallardos y valientes:
Por tierra entre las yervas emboscados,
Pintados de colores differentes,
Andavan levantando bozeria,
Cubiertos de muy rica plumeria.

"Por este braço estrecho, y chico rio
Llegamos con favor de la marea
A la primera casa, y al buhio
Que es dicho Taboba, de paja y nea:
Los Indios luego salen con gran brio,
Con arcos y con flechas de pelea,
Y viendo los rescates acudieron,
Y mucho bastimiento nos vendieron."
—Barco Centenera, Canto XII.

"Tres casas y buhios se dexaron
Con dozientas fanegas bien colmadas
De maiz, y otras casas que se hallaron,
Y estavan so la tierra sepultadas . . ."
—Barco Centenera, Canto XV.

QUERANDÍ

"llegamos al carcarañal . . . bino. vna de jente del campo que se dizen quirandies. esta es jente muy ligera. mantienense de la caza que matan. y en matandola qualquiera que sea le beben la sangre porque su principal mantenimiento es a cavsa de ser. la tierra muy falta de agua. esta jeneracion. nos dio, muy buena Relaçion de la SyeRa y del Rey Blanco.[104] y de otras muchas. jeneraçiones disformes de nra. naturaleza. lo qual. no escribo por parezer cosa de fabula asta que plazo. a dios nro. Señor lo quente y como cosa de vista y no de oydas. Estos quirandies. son tan ligeros que alcançan vn benado por. pies. pelean. con arcos y flechas y con. vnas pelotas de piedra redondas como vna pelota y tan grandes. como el puño. Con vna querda atada. que la guia. las quales tieran tan zertero que no hieran. a cosa que tiran."—Carta de Luis Ramírez, after Outes, 1897.

". . . vinieron ciertos indios de la nación de los querandíes, los cuales son enemigos de los chandules é son vecinos del pié de la sierra donde tenía relación que había la dicha riqueza los cuales le dieron más larga relación de la quél tenía de las dichas requezas y les mostraron ciertos plumajes que traían en la cabeza, hechos, á su parecer deste declarante, de oro bajo é buena plata, é que este declarante se quisiera ir con ellos con la gente que tenía presta é les rogó que lo hobiesen por bien, los cuales no quisieron. porque decían que no podrían sufrir el trabajo del camino, porque en ocho jornadas no fallarían agua; y este declarante les dijo que como ellos venían, que así irían ellos, los cuales dijeron que ellos se sufrían dos ó tres días sin beber é cuando bebían era sangre de venados que mataban para este efecto. . . ."—Sebastián Caboto. in Medina, 1908, Vol. II, p. 159.

". . . . los *Gurandos*, que es un generaçion de indios que son caçadores de venados, é son tan sueltos, que los toman por píes.

". . . . Estos guyrandos son flecheros, é no tienen pueblos, sino que de unos partes á otros andan con sus mugeres é hijos é lo que tienen. Sus casas son un amparo, como de medias choças de cueros de los venados é animales que matan, muy pintados é adobados para defensa del ayre é del agua; é aquesto son sus moradas . . . vereys questos guyrandos son assi como aquellos gigantes (del

[104] That is, the Inca.

Estrecho de Magallanes), aunque el Santa Cruz no diçe que los guyrandos sean tan grandes. Mas diçe que son mayores que los alemanes."—Oviedo, Lib. XXIII, Cap. III.

"Mas adentro [de los tinbus] en la tierra metida está otra generaçion que le llaman *quiranys*, y contractan con ellos pellejos de cabiles, y obejas, y mantas de diversas maneras, y çestas de berguitas, tan texidas y apretadas, que pueden tener agua en ellas, y son muy gentiles en la labor . . . y los tirandis tienen las bolas ya dichas y son muy diestros en ellas. No tienen leyes; y andan en la tierra rasa, y es gente robusta y de color morena, y viven de caça."—Oviedo, Lib. XXIII, Cap. XII.

"Here [Buenos Aires], also we found a place inhabited by Indian folk, named Carendies, numbering about three thousand people, including wives and children, and they were clothed in the same way as the Zechurias,[105] from the navel to the knees. They brought us fish and meat to eat. These Carendies have no houses, but wander about, as do the Gipsies with us at home, and in summer they oftentimes travel upward of thirty miles on dry land without finding a single drop of water to drink.

"And when they meet with deer or other wild beasts, (when they have killed them) they drink their blood. Also if they find a root, called Cardes,[106] they eat it to slack their thirst. This—namely, that they drink blood—only happens because they cannot have any water, and that they might peradventure die of thirst. . . .

"The said Carandies use for their defense hand-bows and tardes[107] which are made in the shape of half-pikes, and the head of them is made out of flint-stone, like a flash; they have also bullets made out of stone with a long piece of string attached to them, of the size of our leaden bullets at home in Germany.

"They throw such bullets around the feet of a horse or a deer, causing it to fall; also it is with these bullets that they killed our commander and the noblemen, as I have seen it done myself, but the foot-soldiers were killed by the aforesaid tardes.

". . . At this place of theirs we found nothing but furrier-work made from marten or so-called otter; also much fish, fish meal, and fish fat There we remained three days and then returned to our camp, leaving on the spot one hundred of our men, in order that they might fish with the Indians' nets for the providing of our folk, because there was there very good fishing. . . .

"At this time the Indians came in great power and force, as many as twenty-three thousand men, against us and our town of Bonas Acieres. There were four nations of them, namely Carendies, Zechurias, Zechuas, and Diembus. . . .

". . . Their arrows are made out of cane, and carry fire on their points.

"They have also a kind of wood, out of which they also make arrows, which, being lighted and shot off, do not extinguish, but also set fire to all houses made out of straw."—Schmidel, 1891, pp. 7–11.

[105] Of the Zechurias (Charrúa) he writes that they "go quite naked, the women having only their privities covered, from the navel to the knee, with a small piece of cotton cloth."

[106] *Cardo*, i. e. thistles.

[107] Darts.

"Es toda aquella tierra muy llana, los campos son tan anchurosos y dilatados, que no hay en todos ellos un árbol: es de poco agua, de mucha caza de venados, avestruces y gran copia de perdices, aunque de pocos naturales: los que hay son belicosos, grandes corredores y alentados, que llaman Querandíes; no son labradores, y se sustentan de sola caza y pesca, y así no tienen pueblos fundados, ni lugares ciertos mas de cuanto se les ofrece la comodidad de andar de ordinario esquilmando los campos. Estos corren desde Cabo Blanco hasta el Rio de las Conchas, que dista de Buenos Aires cinco leguas arriba, y toma mas de otras sesenta la tierra adentro hasta la Cordillera, que vá desde la mar bojeando hácia el norte, entrando por la gobernacion de Tucuman. Estos indios fueron repartidos con los demas de la comarca á los vecinos de la Trinidad, que es el mismo que llaman Buenos Aires."—Díaz de Guzmán, 1882, pp. 29–30.

"Llegamos á una gente Querandiana.
"Salieron a nosotros prestamente,
Que en esto del rescate estan cursados.
Delante de nosotros diligente,
Pescaba cada cual muchos pescados:
Ninguno en los vender era inocente,
Que son en el vender muy porfiados.
Despues mucho maiz en abundancia
Traxeron par gozar de la ganancia."

—Barco Centenera, canto XII.

"El país donde se fundó la nueva colonia de españoles, era suelo nativo de la bárbara nacion de los querandies que por la costa se estendia hasta el cabo Blanco y por tierra adentro llegaba hasta las famosas cordilleras del reino de Chile, discurriendo vagos, al modo de los tártaros, por aquellos anchurosos campos, sin tener morada fija, por que sus casas portátiles reducidas á cuatro cueros de fieras ó de ciertas esteras, se mudaban segun la comodidad que hallaban para la caza, durmiendo donde les cogia la noche, siempre peregrinos y siempre en su patria."—Lozano, Vol. II, p. 83.

"La nacion de los *querandies* fué celébre al tiempo de la conquista por su valor, por su número y por su barbaridad. Hoy con nombre de *Pampas*, se conserva igualmente bárbara, pero menos numerosa. Viven en la gobernacion del Rio de la Plata, y algunas parcialidades en la del Tucuman, y su morada es como gente exenta de leyes, de jurisdicion y república pór donde quiera que mejor les parece. A veces se retiran la campaña adentro, mas de doscientas leguas de Buenos Aires hacía el estrecho de Magallanes, otros se acercan segun su antojo.

"Sus casas son uñas pequeñas chozas, armadas á mano en cuatro palos, y cubiertas con cueros de yeguas ó caballos, cuyas carnes son su mas usual alimento, por lo cual hieden asi sus ranchos como sus personas causando mucho asco. Es gente membruda y de mucha fuerzas, finísimos ateistas, pero se suelen llamar con nombres de cristianos, de lo que se precian con ejecutoria de su nobleza, por parecerse á los españoles con quienes profesan amistad sino otro reconocimiento, como al contrario, son enemigos jurados de los indios serranos que viven en la cordillera hácía Chile.

"Sus armas, muy temidas, son bolas de piedras juegan con singular destreza y acierto, y no es menor su habilidad para el manejo del caballo. Por cada pariente que se muere, se cortan sus dedos el artejo de un dedo, y persiguen al hechicero que es su médico, porque siempre creen vino la muerte por maleficio suyo, y no paran hasta que le privan de la vida; pero es cosa por cierto rara, que lo mismo es matar á un mago de estos que salir varios á pretender el officio, sin saber que en habiendo otro muerto han de procurar matarle sus duedos y amigos; pero ese trago ó no se le representa muy amargo, ó no creen han de sucederles, á á [*sic*] trueque de gozar por algun tiempo los gages de su empleo, que son algunos. Tanto ciegan el interés y la ambicion á estos miserables."—Lozano, Vol. I, pp. 431-32.

CHARRÚA

"Sendo 2 leguas dond'e partira, saíram da terra a mim 4 almadias, con muita gente: como as vi puz-me á corda com o bergantim para esperar por ellas: remavam-se tanto, que parecia que voavam. Foram logo comigo todos; traziam arcos e frechas e azagaias do pao tostado, e elles com muitos penachos todos pintados de mil cores; e chegaram logo sem mostrarem que haviam medo; senam con muito prazer abraçando-nos a todos: a fala sua não entendiamos; mem era como a do Brasil; falavam do papo como mouros: as suas almadias eram de 10, 12 braças de comprido e mea braça de largo: a pao dellas era cedro, mui bem lavradas: remavam-nas com hũas pás mui compridas; no cabo das pás penachos e borlas de penas; e remavam cada almadia 40 homẽs todos em pé: e por se vir a noite nam fui ás sus tendas, que pareciam en hũa praia defronte donde estava; e pareciam outras muitas almadias varadas en terra: e elles acenavam que fosse lá, que me dariam muita caça; e quando viram que nam queria ir, mandaram hũa almadia por pescado: e foi e veo em tamanha brevedade, que todos ficamos espantados: e deramnos muito pescado: e eu mandeilhes dar muitos cascaveis e christallinas e contas: ficaren tão contentes e mostravam tamanho prazer, que parecia que queriam saír fóra do seu siso: e assi me despedi delles."[108]—Pedro López, pp. 47–48.

". . . e 2 leguas do dito rio de Sam João achei a gente, que á ída topára nas tendas; e safrem-me 6 almadias, e todas sem armas. . . . lhe parecia que eram 600 homẽs; e que aquillo, que pareciam tendas que eram 4 esteiras, que faziam hũa casa em quadra, e em riba eram descobertas: e fato lhe nam vira; senam reides da feição das nossas. Como vi isto me despedi delles; e lhes dei muita mercadoria; e elles a nós muito pescado. E vinham apoz de nós, hũs a nado e outros em almadias, que nadam mais que golphinhos; e da mesma maneira nós com vento á popa muito fresco:—nadavam tanto quanto nós andavamos. Estes homẽs sam todos gentes grandes e nervudos; e parece que tem muita força. As molheres parem todas mui bem. Cortam tambem os dedos como os do cabo de Santa Maria; mas nam sam tam tristes."—Pero López, pp. 57–58.

"E andando pela terra[109] em busca de lenha para nos aquentarmos fomos

[108] This applies to country a few leagues west of Montevideo.

[109] Near the "Rio Begoais," which Pero López located 11 leagues west of Cabo de Santa María, which he places 24 leagues from San Pedro (Montevideo). It is identified by de Castro as the Río Solís Grande.

dar n'hum campo con muitos pãos tanchados e reides, que fazia um cerco, que me pareceu á primeira que era armadilha para caçar veados; e despois vi muitas covas fuscas, que estavam dentro do dito cerco das reides: Entâo vi que eram sepulturas dos que morriam: e tudo quanto tinham lhe punham sobre a cova; porque as pelles, com que andavam cobertos, tinham ali sobre a cova, e outras maças de pão, e azagaias de pão tostado, e as reides de pescar e as de caçar veados: todos estavam em contorno da sepultura, e quisera mandar abrir as covas; depois houve medo que acudisse gente da terra, que o houvesse por mal. Aqui juntas estariam 30 covas. Por nam podermos achar outra lenha mandei tirar todolos pãos das sepulturas: mandei-os trazer para fazermos fogo, para se fazer de comer com 2 veados, que matâmos, de que a gente tomou muito consolaçam. A gente desta terra sam homês mui nervudos e grandes; de rosto sam mui feos: trazem o cabelo comprido; alguns delles furam os narizes, e nos buracos trazem metidos pedaços de cobre mui lucente: todos andam cobertos com pelles: dormem no campo onde lhes anoitece: não trazem outra cousa comsigo senam pelles e reides para caçar: trazem por armas hum pilouro de piedra do tamanho d'hum falcão, e delle sae hum cordel de hũa braça e mea de comprido, e no cabo hũa borla de penas d'ema grande; e tiram com elle como com funda: e trazem hũas azagaias feitas de pão, e hũas porras de pão do tamanho de hum covado. Nam comem outra cousa senam carne e pescado: sam mui tristes; o mais do tempo choram. Quanda morre algum delles segundo o parentesco, assi cortam os dedos—por cada parente hũa junta; e vi muitos homês velhos, que nam tinham senam o dedo polegar. O falar delles he do papo como mouros. Quando nos vinham ver nam traziam nenhũa molher comsigo; nem vi mais que hũa velha, e como chegou a nós lançou-se no chão de bruços; e nunca alevantou o rostro: com nenhua cousa nossa folgavam, nem amostravam contentamento com nada. Se traziam pescado ou carne davam-no-lo de graça, e se lhe davam algũa mercaderia nam folgavam; mostrâmos-lhe quanto traziamos; nam se espantavam, nem haviam medo a artelharia; senam suspiravam siempre; e nunca faziam modo senam de tristeza; nem me parece que folgavam com outra cousa."—Pero López, pp. 62–63.

"La gente que aqui habita esta parte
Charuahas se dicen, de gran brio,
A quien ha repartido el fiero Marte
Su fuerça, su valor, y poderio.
Lleva entre esta gente el estandarte,
Delante del Cacique, que es su tio,
Abayuba, mancebo muy loçano,
Y el Cacique se nombra çapicano.

"Es gente muy crecida y animosa,
Empero sin labrança y sementera:
En guerras y batallas belicosa,
Osada y atrevida en gran manera.
En siendo les la parte ya enfadosa
Do viven, la desechan, que de estera

La casa solamente es fabricada,
Y assi presto do quieren es mudada.

"Tan sueltos y ligeros son, que alcançan
Corriendo por los campos los venados;
Tras fuertes abestruzes se abalançan,
Hasta dellos se ver apoderados;
Con unas bolas que usan, los alcançan
Si ven que estan a lexos apartados;
Y tienen en la mano tal destreza,
Que aciertan con la bola en la cabeça.

"A cien passos que es cosa monstruosa
Apunta el Charuaha adonde quiere,
Y no yerra ni un punto aquella cosa
Que tira; que do apunta alli la hiere:
Entre ellos aquel es de fama honrosa,
A cuyas manos gente mucha muere,
Y tantas, cuantos mata, cuchilladas
En su cuerpo se dexa señaladas.

"Mas no por esso dexa de quitare
Al cuerpo del que mata algũn despojo:
No solo se contenta con llevare
Las armas o vestidas a que echa el ojo,
Que el pelejo acostumbra desolare
Del rostro, que maldito y crudo antojo,
Que en muestra de que sale con victoria
La piel lleva, y la guarda por memoria.

"Otra costumbre tienen aun mas mala
Aquestos Charuahaes, que en muriendo
Algun pariente, hazen luego cala,
En si proprios su carne dividiendo;
Que de manos y pies se corta y tela
El numero de dedos, que perdiendo
De propinguos parientes va en su vida,
El Charuaha por orden y medida."

—Barco Centenera, canto X.

"Vinieronse huyendo seis soldados,
Y no pudieron mas, porque los atan
De noche, y dizen quedan treynta vivos,
Que despues que una vez prenden, no matan.
Con ellos no se muestran muy esquivos,
Y si les sirven bien, no los maltratan;
Pero si sirven mal, a rempuxones
Les fuerçan a que salgan de harones."

—Barco Centenera, canto XI.

". . . The *Charuas* go very thinly clad, and have no fixt abode. They are generally seen on horseback, armed with a bow, and a club or lance. They

manage their horses with surprising address . . . as they are constantly exposed to all weathers, their complexion is much tanned; their hair is very long and greatly in disorder. The chiefs of the people are easily distinguished by small pieces of glass set in their chins. Many have scarce more than a finger or two left on each hand, from a custom they have of lopping off a joint from their fingers, as often as a relation dies. This barbarous and rediculous custom begins to wear out among most of the people. The women have charge of providing all nesessaries for the family. They carry all the household goods, when they remove to another place. Besides this burthen, they commonly have two or three children on their backs, and always go on foot, while the husband rides at ease with no load but his arms and some victuals. They cultivate no lands; wild fruits and cattle, which abound in the country, are the whole of their food."—Cattaneo, 1759, pp. 263–265.

"Los charrúas, cuyos restos se mantuvieron en el pais hasta una época reciente, conservaron su independencia y sus habitos feroces, sin cedar jamás a la influencia civilizadora, ni a los estimulos halagüeños de la sociedad. Estuvieron constantamente en guerra con los españoles por cerca de trescientos años; y aunque ese tribu estaba reducida ya a menos de mil individuos a principios de este siglo, nunca fue totalmente vencida ni dominada.

"Vivían desnudos, como en el estado de naturaleza, cubriéndose únicamente la cintura con algunos pedazos de género o de jerga ordinaria, siendo muy raros los que tenían un *quiapí* o jerga entera para abrigarse aún en el rigor del invierno. Llevaban la cabeza descubierta. Algunos de ellos, se ceñían la frente con un trapo en forma de *vincha*, y otros se ataban el pelo con un tiento. Andaban siempre a caballo, en pelos, con un simple rienda sin freno. Eran sumamente diestros para manejarlo, asi como para el uso de las *boleadoras* que jamas dejaban de traer a la cintura. Entre sus juegos peculiares, tenían predilección por el tiro de *bolas de dos ramales*, el cual consistía en enredales en una estaca clavada a regular trecho (30 pasos de distancia) y con una sola cuarta fuera de tierra . . . Enterraban a los muertos en las inmediaciones de algún cerro, si lo había cerca, haciendo una excavacion de poca profundidad en que ponian el cadáver, cubriendolo preferentemente con piedras, si las había a no muy larga distancia; si no con ramas y tierra. Ponian las boleadoras encima, clavando su lanza a un lado de la sepultura, y al otro lado dejaban el caballo atado a una estaca. Decían ellos que era para el viaje que debía emprender el difunto."—Antonio Díaz, *apud* Leguizamon, 1919, p. 15.

YARÓ

"He that was their chieftain, and is commonly called a sorcerer (whom they call *Cazique*) was clad only in a doe's skin, hanging down from his shoulders; the rest had only a piece of skin wrapp'd around the middle, hanging down before as far as to the knees; the boys and girls were stark naked; upon the head they have nothing but long black hair, as strong as horse–hair; in their ears they have holes, in which they hang either fish–bones, shining like the mother of pearl, or a colour'd feather ty'd to a thread; the boys and girls had likewise white fish–bones or feathers, which they wore on their chins, in holes made for that purpose; they also wore feathers of divers colours ty'd in a string around their necks. The men are much of the same size as the *Euro-*

peans, but not quite so tall, with thick legs and large joints; their faces scarce differ from one another, being rather round than oval, but flat, and of an olive colour. They were armed each with a bow, and a whole handful of arrows, these being accounted the most couragious, and most addicted to sorcery among these *Barbarians:* and these are the same *Yares*, for the conversion of whom father *Anthony Behme* was sent thither, and lives among them to this day, not without great difficulty and danger, they having more than once attempted his life.

"Some of the most robust among 'em had several deep seams on their bodies; these wound they give themselves in their tender age, without the least repining, and wear 'em afterwards as a mark of their courage. The women appear more like devils than rational creatures; their hair hangs loose over their foreheads, the rest twisted in several locks, covering their backs to the hips; their faces are full of wrinkles, with their arms, shoulders, and breasts naked; their ornaments about the neck, hands, and arms are certain fish bones, made like scales of mother of pearl, or large scales of fish. The wife of the *Cazique* wears a triple crown, like the popes, made of straw; their children they wrap, as soon as they're born, in a tyger's skin, give 'em suck only for a short time, and afterwards feed 'em with half raw-meat, out of which they suck the juice.

"The men have a custom, at the death of their nearest kindred, to cut off a finger every time off the left hand; and if one of their daughters dies (provided she be handsome) they make a feast, and drink round out of the skull.

"The 22d [two days later], we went ashore again, to purchase some meat of these *Barbarians;* not above eighteen paces from the bank-side we saw their huts of straw, without any roofs, fix'd upon the bare ground, all their household-stuff consisted of a few tompions hollowed out, which they use as we do our copper and earthen vessels, and a few sticks instead of spits; their bed was a tyger or ox-hide spread upon the ground, except that their *Caziqué* had a net fasten'd at some distance from the ground, on two trees, for his bed, the better to secure himself against the wild beasts and serpents. . . ."—Letter of Father Sepp, dated May, 1691. In Sepp and Behme, 1732, pp. 610–11.

"Among them all, the *Tarosians* [Yarô] and *Charuans* were most obstinate in adhering to their ancient customs; living dispers'd, utterly strangers to husbandry, and any form of government; and so very barbarous that they cut off a joint of a finger at the death of every one of their kindred, so that there are several of them who have nothing left but the bare palm of their hand. Before the coming of the *Spaniards* they liv'd upon ostriches, other fowl, venison, and fish: At present they ride about the plains, there being vast herds of oxen and horses: they feed, for the most part, on beef half raw, generally use slings, and are so expert at them, that they often hit birds flying, and knock down the largest beasts. *F. Romero* ventur'd among them attended only by one *Spaniard* and a few *Indians* that row'd: Wheresoever they went, they met fierce men, with their bodies anointed, their hair hanging below their shoulders, their limbs deformed with much pricking of them, and formidable for their hideous voices."—Del Techo, 1732, p. 682.

CHANÁ

"Adelante en la costa de Norte y par del Rio Grande esta otra nasçion que se diçe *chanaes*, salvajes: estos tienen gran abundançia de garrobas que comen, y su habla es muy entonada en el papo, que paresçe que hablan, quando se llaman unos á otros. Tienen varas tiraderas y flechas: no siembran, y son caçadores, de la cual caça y sus garrobas se mantienen."—Oviedo, Lib. XXIII, Cap. XII.

"Los Chanás eran industriosos y hábiles en el trabajo de la ceramica. Por sus ritos funerarios se aseméjaban á los Guaraníes. Como estos disenterraban los cadaveres, una vez que habian perdido sus carnes, para pintar sus huesos con ochre y grasa, y sepultarlos nuevamente con sus avíos. Cuando el muerto era un criatura, la colocaban en un grande urna de barro cocido, que llenaban de tierra y ochre, y tapaban con una especie de plato, tambien de barro cocido." —Azara, 1809, Vol. II, p. 31.

MBEGUÁ

"Adelante destos (*guaranies*), rio arriba hay otra generaçion, que se diçe *beguaes*, que viven en las islas de la parte del Sur en el mismo rio: son poca gente, y quando el rio cresçe, vánse á la Tierra-Firme á la parte del Sur, y susténtanse de pesquerias y siembran algo, como los sussodichos."—Oviedo, Lib. XXIII, Cap. XII.

"Beguaes de la otra vanda conocieron
La cosa del rescate que passava,
A gran priessa a nosotros acudieron,
Temiendo que el rescate se acabava.
Rescatan todo aquello que traxeron,
Y mas dizen en casa les quedava,
A Gaboto de aqui presto se llega,
Por do el Carcaraña se estiende y riega."
—Barco Centenera, Canto XII.

CHANÁ-MBEGUÁ

"Sendo a par das ilhas dos corvos,[110] d'antre hum arboredo ouvimos grandes brados, e fomos demandar onde bradavam: e saía a nós hum homen, á bordo do rio, coberto com pelles, com arco e frechas na mão; e fallou-nos 2 ou 3 palavras guaranís, e entenderam-as os linguas, que levava; tornarem-lhe a falar na mesma lingua, nam entendeu; senam disse-nos que era *beguoaa chanaa* e que se chamava *ynhandú*. E chegamos com o bergantim a terra, e logo vieram mais 3 homês e hũa molher, todos cobertos com peles: a molher era muy fermosa; trazia os cabellos compridos e castanhos: tinha hũs ferretes que lhe tomavam as olheiras: elles traziam na cabeça hũs barretes das pelles das cabeças de onças, com os dentes e com tudo. Por acenos lhe entendemos que estava hum homen com outra geraçam que chamavam *chanás*, e que sabia falar muitas linguas; e que o queria ir a chamar, e estava la diante pelo rio arriba; e que elles íriam e viriam em 6 dias. Entam lhes dei muitas cristalines e contas e cascaveis, de que foram mui contentes, e a cada hum delles seu barrete vermelho; e á molher hũa camisa: e como elhes isto dei, foram a

[110] That is, at the mouth of the Paraná.

hũs juncais. e tirarem duas almadias pequenas, e trouxeram-me ao bargantim pescado e taçalhos de veado, e hũa posperna d'ovelha. . ."—Pero López. pp. 55-56.

CHANÁ-TIMBÚ

"Dentro del embocamiento del rio de la Plata, en la parte ques mas austral dél, en la costa que está enfrente de los indios que llaman *janaes beguaes*, á la banda del sur, está la gente que llaman *janaes timbus*, y toda es una lengua."—Oviedo, Lib. XXIII, Cap. V.

". . . y mas adelante en la mesma costa. passando el rio Nero, está otra gente que se diçe *chanastinbus*, que viven en las islas de la costa ya dicha, y que se mantienen de pesqueria y siembran algun poco de mahiz y calabaças de las nuestras de España, pero mayores; é tienen muchas pieles de nutras y buenas, y venados grandes y pequeños. . . . Los chanastinbus son de alta estatura mas que los otros. y los guaranies son de estatura de los españoles: todos andan desnudos, salvo los tinbus que se cubren con los pellejos ya dichos."—*Ibid.*, Cap. XII.

TIMBÚ

"las mujeres de estos timbúes tienen por costumbre de cada vez que se les muere algun hijo ó pariente cercano, se les cortan una coyuntura de un dedo y tal mujer hay de ellas que en las manos ni en los pies no tienen cabeza en ningún dedo y dicen que lo azen á cabsa del gran dolor que sienten por muerte de tal persona."—Ramírez in Madero, 1892, p. 342.

"Adelante desto [*beguaes*] está la gente de los tinbus, á par de un estero que sale del rio grande por junto á la Tierra-Firme y parte del Sur; y á par destos está una nasçion que llaman *carcaraes*, que es gente alta de cuerpo, y la una y la otra de lenguas differentes, que en el trato paresçe mejor que las otras ya dichas. Susténtanse de pescado, y tienen mucho y bueno; y sacan del mesmo pescado mucha y buena mantecca, de que los chripstianos se aprovechan mucho, assi en su comer como para arder en los candileş, y para aderesçar los cueros de venado, de que haçen vestido y calçado y cueras para su defensa. Estos tienen muchos venados. y avestruçes. y ovejas de las grandes del Perú, tigres, nutrias y ostros animales que quieren paresçer conexos, é otros de otras maneras. . . . Estos tinbus y carcaraes son de mayor estatura que los tirandis (Querandí) y que todos los ya dichos. y es gente sofrible y amorosa y amiga de los chripstianos, aunque son flecheros. cuyas flechas son pequeñas y emplumadas de tres plumas y muy polidas. Tienen tiraderas, de que se sirven como de dardos. . . . Los tinbus tienen çiertas lagunas. en que tienen grandes pesquerias. y les sacen pescado y lo guardan para el tiempo de adelante. Tienen muchos perros, como los nuestros grandes y pequeños, que ellos estiman mucho, los quales allá no avia, y se han hecho de la casta que quedó quando Sebastian Gaboto y el capitan Johan de Junco anduvieron por aquella tierra. Sus casas son de esteras con sus apartamientos y muy bien hechas, é tienen guerra con los baranis (Guaraní) caribes."—Oviedo, Lib. XXIII, Cap. XII.

". . . and in two months' time we reached the Indians, at a distance of eighty-four miles. These people are called Tyembus; they wear on either nostril a small star made out of white and blue stones. The men are tall of stature and erect, but the women, on the contrary, young and old, are very deformed, having all the lower part of their faces scratched, and always bloody. These people have nothing else to eat, and have all their lives through lived upon nothing else but fish and meat. They are reckoned to be fifteen thousand strong, or more And when we came to about four miles' distance from this people they took notice of us, and came to meet us in sign of peace, with over four hundred canoes, in each of which were sixteen men.

"Such a skiff is made out of a single tree, eighty feet long and three wide, and must be rowed as the fishermen's boats in Germany, only that the oars are not bound with iron.

". . . the chief of the Tyembus Indians, Zchera Wassu[111] . . . gave us there fish and meat in abundance.

"In this said place we abode four years"—Schmidel, 1891, p. 12.

"So then departing from the haven of Bonesperanzo[112] with the said eight Parchkadienes[113] vessels, we reached the first day, after a voyage of four miles, a nation called Cuaranda, who abstain from [*sic*] fish and meat, and number over twelve thousand men, all of whom are fit for war. These people resemble the Thiembus spoken of before; they have little stones on their noses, and the men are tall, but the women are hideous; young as well as old have their faces scratched and always bloody. They are clothed like the Thiembus, from the navel to the knee with a small cotton cloth, as was described before. These Indians have great plenty of otter skins: also many canoes or skiffs. They liberally parted with us their fish, meat, and skins . . ."—Schmidel, 1891, p. 15.

"Sailing further we came afterwards to another people called Gulgaises[114] who number forty thousand men of war and abstain from [*sic*] fish and meat. These have also two little stars on their noses; they are situated thirty miles from the Curandas, and speak the same language as the Thiembus and Curandas. They dwell on a lake six miles long and four miles wide on the left side of the river Paranau."—Schmidel, p. 15.

". . . Otros hay mas arriba, que llaman Timbúes y Carcarás 40 leguas de Buenos Aires en Buena Esperanza que son mas afables y de mejor trato y costumbres que los de abajo. Son labradores, y tienen sus pueblos fundados sobre la costa del rio: tienen las narices horadadas, donde sientan por gala en cada parte una piedra azul ó verde: son muy injeniosos y hábiles, y aprenden bien la lengua éspañola: fueron mas de 8000 indios antiguamente, y ahora han quedado muy pocos."—Ruy Díaz de Guzmán, 1882, pp. 30-31.

"Otras islas estan tan bien pobladas
De gentiles naciones y gentio,

[111] *Chera Guazú* in Guaraní means "great chief."

[112] Buena Esperanza or Corpus Christi was four leagues below Sancti Spiritus, the settlement of Sebastian Cabot on the Carcarañá river.

[113] Brigantines.

[114] Quiloazas.

Timbues las mas de ellas son llamadas,
Que muy poco temor tienen al frio,
La torre de Gaboto esta cercana
Y la gente llamada Cherandiana."
—Barco Centenera. Canto II.

". . . . y las islas que ha formado,
Habitan los Timbus. gente amorosa,
Sagaz, astuta, fuerte. bellicosa."
—*Ibid.*, Canto XII.

"From Santo Spirito unto a people which are called Los Tenbuis is fifteen leagues. This is by the narrow (northern) arme whereby they passe into the river Parana: it is the more narrow because it is the longer way. From the Tenbuis by this narrow arme upward unto the Quiloacas. which is another nation, are twentie leagues; and all up this river is great store of people.

"From the Quiloacas, to a place where the Spaniards now have builded a towne (Santa Fé), are fifteen leagues."—A ruttier, p. 100.

"'Twas formerly very remarkable among other customs of the natives, that the women were not allow'd to paint their bodies with a clay colour till they had tasted human flesh. If they had not prisoners taken in war, they would cut the dead bodies of their own people in pieces. and give 'em to the young maids to eat. They planted trees over the graves of their ancestors, and adorn'd 'em with ostrich feathers, and met there at certain times to lament."—del Techo. 1732, p. 666.

"Formerly there were no great towns upon the *Parana*, but the people liv'd dispers'd in villages. Both sides of the river, running a vast extent, are inhabited by several nations, all, except the *Guairanians*, as like one another in manners and barbarity as they are remarkable for diversity of language. Among 'em all, I think those very remarkable who feed upon a certain sort of earth. dry'd at the fire, and then dipp'd in the fat of fish; so that there is little cause to admire they should think so little of heaven, who find so great a relish in earth."—del Techo, 1732, pp. 667–68.

"Los *timbucs. quiloasas y colastinés*, eran naciones del distrito de Santa-Fé, que por pestes ó guerras, se estinguieron del todo. Eran caribes antes de domesticarse con el commercio de los españoles. Pintábanse los cuerpos con barro, asi hombres como mujeres; pero á estas no les era lícito usar de la pintura antes de probar carne humana. y si por ventura no hallaban cadáver de algun cautivo en que cebarse destrozaban el de alguno de su nacion, paraque las muchachas pudiesen usar cuanto antes la mejor gala de su desnudez.

"Los sepulchros de sus padres. los adornaban con plumas de avestruz y en cada uno plantaban un ombú, árbol bien que frondoso pero muy triste, y acudia allí toda la parentela de tiempo en tiempo á planir sentidamente al difunto. Hacian de barro unos bollos que freian de grasa de pescado, y era el manjar mas regalado en sus banquetes; con que no es de admirar viviesen olvidados de las cosas del cielo, los que gustaban de tanto la tierra. . ."—Lozano, Vol. I, p. 428.

"Traia el indio por morrion, un cuero de anta en la cabeza; por escudo, una concha grande de cierto pescado, su carcaj y arco á las espaldas, y en las manos un baston proporcionado á la altura desmedida de su cuerpo. . ."—Lozano, Vol. III, p. 161.

APPENDIX II

Distribution of Tribes

The geographical distribution of tribes of the R. La Plata and Paraná delta is a perplexing problem, because the early historical sources fail to assign definite boundaries and because these records are conflicting. It is therefore impossible to draw a completely satisfactory ethnographical map, as the available evidence is open to individual interpretations. For this reason we summarize the data on which our Pl. II has been based.

GUARANÍ

1.—According to Oviedo (*180*, Lib. XXIII, cap. XII), they lived on the south side of the delta.

2.—According to Santa Cruz (*201*, pp. 56–57) they occupied the islands of the R. La Plata, and this is confirmed by archeological evidence (*171*, *175*).

3.—According to Cabot (*159*, p. 182) they extended upstream to within 12 leagues of the Carcarañá river.

CHARRÚA

1.—García, Oviedo, and Schmidel located the Charrúa on the western shore of the R. La Plata.

2.—After the Conquest, part of the Charrúa crossed the Uruguay and lived between that stream and the Paraná in what is now the Province of Entre Ríos, where they are shown on several contemporary maps. Falkner's map calls the present Arroyo Nogoya by the name "R. de Charuas." Lozano (*125*, I, p. 139) states that the Franciscan fathers had a large Charrúa mission on the Carcarañá river, where Falkner's map places a mission called San Miguel. In 1762 there was founded the town of Concepción de los Charrúas (*33*) on the east bank of the Paraná near Santa Fe.

QUERANDÍ

1.—According to Ramírez[115] they lived near the Carcarañá river.

2.—According to García[116] they lived behind, i. e., southwest of the Carcarañá tribe.

3.—According to Schmidel[117] they occupied the site of Buenos Aires.

4.—According to Díaz de Guzmán (*53*, p. 30) they occupied the coast from Cabo Blanco to the Río de las Conchas and extended seventy leagues inland towards Tucuman.

5.—Lozano (*125*, II, p. 83) states that they extended from Cabo Blanco to the *Cordilleras* of the Kingdom of Chile, i. e., to Mendoza.

CHANÁ

1.—They lived near the Carcarañá river, according to Ramírez.[118]

2.—Oviedo (*180*, Lib. XXIII, cap. XII, p. 192—quoted in Appendix I, p. 209) writes that they lived "on the north shore and beside the big river."

[115] Appendix I, p. 201.
[116] Appendix I, p. 197.
[117] Appendix I, p. 202.
[118] Appendix I, p. 197.

3.—Oviedo (*180*, Lib. XXIII, cap. V) also speaks of a river "of Janaes" entering the Paraná 10 leagues above the river "of Carcaraes," i. e., somewhere near Santa Fe.

4.—Indians encountered by Pero López (*117*, p. 25—quoted in Appendix I, p. 200) at the mouth of the Paraná told him the Chaná lived several days' journey upstream. Azara and later writers say that they inhabited the islands in the Uruguay at the mouth of the Río Negro.

From this evidence it appears that the Chaná lived in two enclaves, one near the mouth of the Paraná, on the north shore, the other near Santa Fe. This division persisted in the colonial epoch. as appears from what follows.

5.—"In the middle of the XVII century, Father Bernardo Guzmán converted them to Christianity, forming with them the missionary settlement of Santo Domingo Soriano, which, in 1708, was moved to the left bank of the Río Negro" in Uruguay (*60*, p. 132).

6.—The *repartamiento* of 1678 speaks of "Chanas who were natives of the town and mission of Baradero" on the Paraná (*159*, App. VIII, p. 169).

7.—A map dated 1688 shows "Chanas" between the Uruguay and Paraná rivers.[119]

MBEGUÁ

1.—Ramírez[120] writes that they lived in the neighborhood of Sancti Spiritus. that is, near the Carcarañá river.

2.—According to Oviedo (*180*, Lib. XXIII, cap. XII) the Mbeguá lived upstream from the Guaraní and below the Timbú.

3.—The map of Desceliers[121] (1550) shows "Beguas" between the quirandis river (Arroyo del Medio) and the Carcaram (Carcarañá).

4.—According to Lozano (*125*, III. p. 271) the Mbeguá were settled in Baradero after the Conquest. and a few of them still survived in the seventeenth century.

5—"All the other armes containe likewise sixteene leagues in length, save one small one or narrow arme, which is called The river de los Beguaes; for this containeth fortie leagues in length (*198*, p. 99).

CHANÁ–MBEGUÁ

1.—Oviedo (*80*. Lib. XXIII, cap. V—quoted under Chaná-Timbú) states that they lived inside the river mouth opposite the Chaná–Timbú.

2.—Pero López da Souza met "beguoaa chanaa" at the lower end of the delta.[122]

CHANÁ–TIMBÚ

1.—Ramírez[123] says they lived in the vicinity of Sancti Spiritus, that is, near the Carcarañá river.

2.—García[124] writes that they lived next the Carcaraes.

[119] Reproduced in Torres Lanzas, 1921. map 32.
[120] Appendix I, p. 197.
[121] Reproduced in Outes, 1917, p. 675.
[122] Appendix I, p. 200.
[123] See Appendix I, p. 197.
[124] See Appendix I, p. 197.

3.—Oviedo[125] states that they lived on the south side of the delta opposite the Chaná-Mbeguá.

4.—Oviedo[126] also says that they lived on the R. La Plata opposite to R. Negro.

5.—López de Velasco (*118*, p. 560) states that the River "Chanaes-Timbues" is five leagues above the River "Querandies" and fourteen leagues below the River "Carzarana."

From this welter, the probability emerges that the Chaná-Timbú and the Chaná-Mbeguá lived respectively on the western and eastern shores of the Paraná below where the city of Rosario stands today.

TIMBÚ

1.—Ramírez[127] places the Timbú near Sancti Spiritus.

2.—Oviedo (*180*, Lib. XXIII, cap. II) says the "Timbuz" river was ten leagues above the Carcaraña river and ten leagues below the Carcaraes river.

3.—Oviedo (*180*, Lib. XXIII, cap. XII) also states that the "tinbus" lived beyond (upstream from) the Mbeguá and beside the Carcaraes.

4.—Ruizdíaz (*53*, p. 30) places them near Buena Esperanza.

5.—Lozano (*125*, I, p. 428) lists them as natives of the district of Santa Fe.

6.—The "island" of the "Tinbu," mentioned by Schmidel. is still known by that name. It lies in front of the mouth of the Carcarañá river. On the opposite side of the delta are the Arroyos Timbo Colorado and Timbo Blanco.

APPENDIX III

Colonial Missions

The missionary settlements near Buenos Aires and Santa Fe, the dates of their founding, the tribes which lived in them, and their population about the year 1770, appear in the following table. It is based chiefly on Azara, Lozano, the *Breve relación*, documents printed by Lehmann-Nitsche (1922), and the *Estadística* of 1869.

[125] "Dentro del embocamiento del rio de la Plata, en la parte ques mas austral dél. en la costa que está enfrente de los indios que llaman *janaes beguaes*, á la banda del sur, está la gente que llama *janaes timbus*, y toda es una lengua."—Oviedo, Lib. XXIII, Cap. V.

[126] ". . . y mas adelante en la mesma costa. passando el rio Nero, está otra gente que se diçe *chanastinbus*, que viven en las islas de la costa ya dicha. . . . "—Oviedo, Lib. XXIII, Cap. XII.

[127] See Appendix I, p. 197.

TABLE VIII

Date	Settlement	Tribe	Population	Date
1580	Santiago del Baradero	Guaraní, Mbeguá, Chaná	121 families, 711 individuals	1770
1618	Santa Cruz de los Quilmes	Calchaquí[128]		
1650	Santo Domingo Soriano	Chaná		
1622	San Lucas (Río de Areco)	Mbeguá	228 individuals	1622
1740	Nra. Sra. del Rosario de los Calchaques	Calchaquí[129]	5 families, 70 individuals	1770
1740	Pueblo de la Concepción	Pampas	40 families, 350 individuals	1770
1753	San Javier de Macobis	Macobí	200 families, 1006 individuals	1770
1758	San Jerónimo de Abipones	Abipones	120 families, 600 individuals	1770
1762	Concepción de los Charruas	Charrúa	64 families, 320 individuals	1770
	(Río Carcarañá) San Miguel	Charrúa		
	(Río Arrecifes)	Caiguan		
	(Río de las Conchas)	Guacunambí (Querandí?)		
	Jesús María	Minuane		
	San Borja	Minuane, Guaraní		

Missionary Settlements Near Santa Fe and Buenos Aires.

[128] "A cuatro leguas de Buenos Aires, está sobre la costa el pueblo de los indios *quilmes*, parcialidad la mas belicosa y rebelde contra el español que produjo el Vallo (*sic*) de Calchaquí de donde despues de sujetarles por armas, año de 1665, el gobernador don Alonso Mercado, los transplantó en número de dos mil á este sitio; pero hoy apénas trendá veinte familias este puebo."—Lozano, Vol. I, p. 153.

[129] "Los calchaquíes de hacía Santa Fé, distintos de otra nacion del mismo nombre en la provincia de Tucuman."—Lozano, Vol. I, p. 134. The names of Laguna Calchaquí and Río Calchaquí in the Province of Santa Fe indicate the location of this tribe. Charlevoix (Vol. I, p. 210) writes that both groups came from the Calchaquí valley after their defeat by Alfonso Mercado y Villacorte in 1565 [*sic*].

BIBLIOGRAPHY

Acevedo Díaz, Eduardo

(*1*) 1891. Etnología indígena. La raza charrúa á principios de este siglo. In *Revista Nacional*, T. XIV, Buenos Aires

Acusación del Fiscal

(*2*) 1908. Acusación del Fiscal de su Majestad contra Sebastián Caboto . . . sobre varios excesos que cometió . . . 4 de Febrero de 1532. In Medina, 1908, II, pp. 179-217.

Aguirre, J. F. de

(*3*) 1905. Diario. In *Anales de la Biblioteca*, T. IV, Buenos Aires.

Ambrosetti, J. B.

(*4*) 1893. Sobre una colección de alfarerias minuanes recojidas en la provincia de Entre-Ríos. In *Bol. Inst. Geogr. Arg.*, T. XIV, Buenos Aires.

(*5*) 1894. Los paraderos precolombianos de Goya (provincia de Corrientes). In *Bol. Inst. Geogr. Arg.*, XV, Buenos Aires.

(*6*) 1895. Los cementerios prehistóricos del Alto Paraná (Misiones). In *Bol. Inst. Geogr. Arg.*, T. XVI, Buenos Aires.

(*7*) 1902. Antigüedades Calchaquíes. Datos arqueológicos sobre la provincia de Jujuy. In *Anales de la Sociedad Científica Argentina*, Tomos LIII and LIV, Buenos Aires.

(*8*) 1904. Apuntes sobre la arqueología de la Puna de Atacama. In *Revista del Museo de la Plata*, T. XII, La Plata.

(*9*) 1906. Exploraciones arqueológicas en la Pampa Grande. *Facultad de Filosofía y Letras, Publicaciones de la Sección Antropológica*, No. 1, Buenos Aires.

(*10*) 1912. Memoria del Museo Etnográfico. 1906 á 1912. In *Facultad de Filosofía y Letras, Publicaciones de la Sección Antropológica*, No. 10, Buenos Aires.

Ameghino, F.

(*11*) 1877. Noticias sobre antigüedades indias de la Banda Oriental. Mercedes.

(*12*) 1880–81. La antigüedad del hombre en La Plata. 2 vols. Paris.

Angelis, Pedro de

(*13*) 1910. Colección de obras y documentos relativos á la historia antigua y moderna de las provincias del Río de la Plata. 5 vols. Buenos Aires.

Aparicio, F. de

(*14*) 1922. Neuvos hallazgos de representaciones plásticas en el norte de la provincia de Santa Fe. In *Revista de la Universidad de Buenos Aires*, T. XLIX, Buenos Aires.

[Araújo, José Joaquín]

(*15*) 1903. Guía de forasteros del Virreinato de Buenos Aires para el año de 1803. Reprinted in *Historia*, I, Buenos Aires.

ARAÚJO, ORESTES

(*16*) 1900. Diccionario geográfico del Uruguay. Montevideo.

(*17*) 1905. El ultimo Charrúa. In *El Iris.* Año I, 2a epoca, No. 6, San Eugenio del Cuarcim.

(*18*) 1908. Significado de la voz "Uruguay." In *Anales de Instrucción Primaria,* V, Montevideo.

ARCHIVO COLONIAL

(*19*) 1914. Archivo colonial, Museo Mitre. Tomo I, Buenos Aires.

ARCHIVO PARROQUIAL

(*20*) 1756-59. Archivo parroquial de Baradero, T. I. (Ms. quoted in Debenedetti, 1911.)

ARRIVÉE

(*21*) 1830. Arrivée de quatre sauvage. etc. Paris.

AZARA, F. DE

(*22*) 1809. Voyages dans l'Amérique Meridionale. Paris.

(*23*) 1904. Geografía física y esférica de las provincias del Paraguay y misiones Guaranies. . . Bibliografía, Prólogo y anotaciones por Rodolfo R. Schuller. In *Anales del Museo Nacional de Montevideo,* I, Montevideo.

BÁEZ, CECILIO

(*24*) 1926. Historia colonial del Paraguay y río de la plata. Asunción.

BARCO CENTENERA, M. DEL

(*25*) 1912. Argentina y conquista del Río de la Plata. Buenos Aires.

BAUZA, FRANCISCO

(*26*) 1895. Habitantes primitivos del Uruguay. Montevideo.

(*27*) 1929. Historia de la dominación española en el Uruguay. 3 vols. Montevideo.

BAYO, CIRO

(*28*) 1913. Los Césares de la Patagonia. Madrid.

BEHME, ANTONY

(*29*) *See* SEPP, ANTONY, *and* BEHME, 1732.

BERMÚDEZ, PEDRO P.

(*30*) 1853. El Charrua. Drama histórico en cinco actos. Montevideo.

BERTONI, MOISES SANTIAGO

(*31*) 1922. La civilización Guaraní. Part I: etnología. Puerto Bertoni.

BOGGIANI, GUIDO

(*32*) 1895. I caduvei (Mbayá o Guaycurú). Rome.

BREVE RELACIÓN

(*33*) 1899. Breve relación geográfica y política de la gobernación del Río de la Plata. In Outes, 1899, pp. 66–79.

BRINTON, D. G.

(*34*) 1891. The American race. New York

(*35*) 1898. Argentine ethnography. In *Science*. VIII, No. 208, New York.

(*36*) 1898a. The Querandíes. In *Science*. VIII, No. 197, New York.

BURMEISTER

(*37*) 1876. Description physique de la Republique Argentine. Paris.

CABOTO, SEBASTIÁN

(*38*) 1908. Declaración de Sebastián Caboto. In Medina, 1908, pp. 158–164.

CAMAÑO, JOAQUÍN

(*39*) Manuscript letters to Hervas. Vat. Lat. 9802. (Extracts have been supplied me through the kindness of Prof. C. U. Clark and the courtesy of the Smithsonian Institution.)

(*40*) 1787. Catecismo brevisimo en la lengua Güenoa. In Hervas, 1787.

CARDOSO, ANIBAL

(*41*) 1920. Breves noticias y tradiciones sobre el origen de la boleadora y del caballo en la República Argentina. In *Anales del Museo National de Historia Natural de Buenos Aires*, T. XXVIII, Buenos Aires.

CARO, GREGORIO

(*42*) 1908. El capitán Gregorio Caro con Sebastián Caboto . . . sobre que no quiso cumplir cierta instrucción de la armada. . . . In Medina, 1908, II, pp. 256-298.

CATTANEO, CAJETAN

(*43*) 1759. The third letter of F. Cajetan Cattaneo. In Muratori, 1759, pp. 253–280.

CHAMBERLAIN, A. F.

(*44*) 1907. South American linguistic stocks. In XV *Intern. Congr. Amer.*, Quebec.

(*45*) 1911. On the Puelchean and Tsonekan (Tehuelchean), the Atacameñan (Atacaman) and Chonoan, and the Charruan linguistic stocks of South America. In *American Anthropologist*, N. S., XIII, No. 3. Lancaster.

CHARLEVOIX, PIERRE F. X. DE

(*46*) 1769. The history of Paraguay . . . written originally in French. 2 vols. Dublin.

CHURCHILL, AWNSHAM *and* JOHN

(*47*) 1732. A collection of voyages and travels. 6 vols. London.

CLAUDE JOSEPH, *Rev. Brother*

(*48*) 1928. Los tejidos Araucanos. In *Revista Universitaria*, Año XIII, Núm. 10 Santiago de Chile.

COLINI, G. A.

(*49*) 1895. Notizie storiche ed etnografiche sopra i Guaycurú e gli Mbayá. In Boggiani, 1895, pp. 286–339.

CUNNINGHAME GRAHAM, R. B.
(*50*) 1924. The conquest of the River Plate. London.

DEBENEDETTI, SALVADOR
(*51*) 1921. La influencia hispánica en los yacimientos arqueológicos de Caspinchango. In *Revista de la Universidad de Buenos Aires*, T. XLVI, Buenos Aires.

DÍAZ, ANTONIO
(*52*) 1877. Historia política y militar de las Repúblicas de la Plata. 2 vols. Montevideo.

DÍAZ DE GUZMÁN, RUIZ
(*53*) 1882. Argentina. Historia del descubrimiento, conquista y población del Rio de la Plata escrita por Ruidiaz de Guzman el año 1612. Buenos Aires.

DOBRIZHOFFER, M.
(*54*) 1822. An account of the Abipones. 3 vols. London.

DUCCI, ZACARIAS
(*55*) 1904. Los Tobas de Taccalagé. Buenos Aires.

ENCOMIENDAS
(*56*) 1897. Encomiendas de la jurisdicción de Buenos Aires y Santa Fé. In Outes, 1897, Appendix 8.

EN UN CEMENTERIO
(*57*) 1925. En un cementerio indígena se desenterraron 35 esqueletos de la época de la conquista In *La Critica*, June 9, Buenos Aires. [An account of the Thea Heye–La Plata excavations at Arroyo Sarandí.]

ESTADÍSTICA
(*58*) 1869. Estadística e historia antiqua. 1768 á 1789. Colección de manuscritos de M. P. Razón de las doctrinas y pueblos de misiones fronterizas de la gentilidad que hay en todas las Indias. . . . In *Boletín de la Sociedad Mexicana de geografía y estadística*, segunda época, T. I, México.

EXCAVACIONES
(*59*) 1925. Las excavaciones de las islas del delta, pueden ser fuente de importantísimos descubrimientos arqueológicos. In *La Crítica*, June 10, Buenos Aires. [An account of the Thea Heye–La Plata excavations at Arroyo Sarandí.]

FIGUEIRA, J. H.
(*60*) 1892. Los primitivos habitantes del Uruguay. Montevideo.
(*61*) 1900. Charrúas. In Araújo, 1900.

FITZROY, ROBERT
(*62*) 1839. Narrative of the surveying voyage of His Majesty's ships *Adventure* and *Beagle* between the years 1826 and 1836. . . . II. Proceedings of the second expedition. London.

FREGEIRO, C. L.

(*63*) 1879. Juan Díaz de Solis y el descubrimiento del Río de la Plata. Buenos Aires.

(*64*) 1893. La historia documental y crítica. In *Revista del Museo de La Plata*, V, La Plata.

FRIEDERICI, GEORG

(*65*) 1906. Skalpieren und ähnliche Kreigs-gebräuche aus Amerika.. Braunschweig.

(*66*) 1915. Ein Beitrag zur Kenntnis der Trutzwaffen der Indonesier, Südseevölker und Indianer. In *Baessler Archiv*, Beiheft. VII, Leipzig and Berlin.

(*67*) 1920. Ursprung und Verbreitung von Lasso and Wurfkugeln. In *Zeitschrift des Deutschen Wissenschaftlichen Verein zur Kultur und Landeskunde Argentiniens*, VI Jahrgang, Buenos Aires.

GARAY, JUAN DE

(*68*) 1915. *See* RUIZ GUIÑAZÚ, 1915.

GARCÍA DE MOGUER, DIEGO

(*69*) 1908. Relación y derrotero de Diego García, que salió de la Coruña en 15 de enero de 1526, en el Mar Occéano, é llegó en 27 [*sic*] al Río Paraná . . . In Medina, 1908a, pp. 232–46.

GRANADA, D.

(*70*) 1890. Vocabulario rioplatense razonado. Montevideo.

(*71*) 1900. El idioma nacional. Montevideo.

GRUBB, W. BARBROOKE

(*72*) 1914. A church in the wilds. New York.

(*73*) 1914a. An unknown people in an unknown land. An account of the life and customs of the Lengua Indians of the Paraguayan Chaco. London.

GUEVARA, JOSÉ

(*74*) 1910. Historia del Paraguay, Rio de la Plata y Tucuman. In de Angelis, 1910, II, Buenos Aires.

GUIDE

(*75*) [N. D.] Guide to the Peabody Museum of American Archaeology and Ethnology. Cambridge.

HAKLUYT, RICHARD

(*76*) 1904. The principal navigations voyages traffiques and discoveries of the English nation. 12 vols. Glasgow.

HARRISSE, H.

(*77*) 1896. John Cabot and Sebastian his son. London.

HERNÁNDEZ, PABLO

(*78*) 1908. El extrañamiento de los Jesuítas del Río de la Plata. In *Colección de libros y documentos referentes á la historia de América*, VII, Madrid.

HERNÁNDEZ, PEDRO
(*79*) 1899. Exposición del escribano . . . de los acontecimientos que habían tenido lugar en la Provincial del Paraguay y Río de la Plata . . . 1545. Cited in Outes, 1899.

HERRERA, A. DE
(*80*) 1601–1615. Historia general de los hechos de los Castellanos en las Islas y Tierra Firme del Mar Oceano. Madrid.

HERVAS, LORENZO
(*81*) 1787. Saggio pratico delle lingue. In *Idea dell' Universo che contiene storia della vita, dell' uomo, viaggio estatico al mondo planetario, e storia della terra, e della lingue.* 24 vols. Cesena.
(*82*) 1800–05. Catálogo de las lenguas de las naciones conocidas. 6 vols. Madrid.

HOLMES, W. H.
(*83*) 1912. Stone implements of the Argentine littoral. In Hrdlička, 1912, pp. 125–152.

HRDLIČKA, ALEŠ
(*84*) 1912. Early man in South America. In *Bur. Amer. Ethn., Bulletin 52*, Washington.

IHERING, H. VON
(*85*) 1895. A civilisação prehistorica do Brazil meridional. In *Revista do Museu Paulista*, T. I, São Paulo.

INFORMACIÓN HECHA
(*86*) 1908. Información hecha por los oficiales de la Casa de la Contratación de Sevilla luego que llegó la armada de Sebastián Caboto, acerca de lo que occurrió en el viaje—28 de Julio de 1530. In Medina, 1908, II, pp. 151-164.

INFORMACIÓN LEVANTADA
(*87*) 1908. Información levantada en Sevilla para averiguar los indios que Diego García y Sebastián Caboto habían llevado á España desde el Río de la Plata.—4 de Deciembre de 1530. In Medina, 1908, II, pp. 172–179.

IRALA, DOMINGO MARTÍNEZ DE
(*88*) 1898. La relacion que dexo domingo miñz de yrala en buenos ayres al tpo q. la despoblo. In Zeballos, 1898.

KERMES, ENRIQUE
(*89*) 1895. Tejidos Pampas. In *Revista del Jardín Zoölógico de Buenos Aires*, I, Buenos Aires.

KROEBER, W. H.
(*90*) 1914. The romance of the River Plate. 2 vols. London.

LAFONE QUEVEDO, S. A.
(*91*) 1897. Los Indios Chanases y su lengua con apuntes sobre los Querandíes, Yaros, Boanes, Güenoas o Minuanes y un mapa étnico. In *Bol. del. Inst. Geogr. Arg.*, XVIII, Buenos Aires.

(*92*) 1897a. El nombre de río de la plata y los comedores de carne humana. In *Bol. Inst. Geogr. Arg.*, XVIII. Buenos Aires.

(*93*) 1898. La raza Pampeana y la raza Guaraní. Progresos de la etnología en el Río de la Plata. Buenos Aires.

(*94*) 1899. Progresos de la etnología en el Río de la Plata durante el año de 1899. In *Bol. Inst. Geogr. Arg.*, XX, Buenos Aires.

(*95*) 1903. Juan Díaz de Solis. In *Historia*, I. Buenos Aires.

(*96*) 1905. Viaje arqueológico en la región de Andalgalá. In *Revista del Museo de la Plata*, T. XII. La Plata.

(*97*) 1909. Etnología Argentina. In *IV Latin American Scientific Congress*, Buenos Aires.

(*98*) 1922. Escritos de don Antonio Dámaso Larrañaga. Los publica el Instituto histórico y geográfico del Uruguay. Montevideo.

Latcham, Ricardo E.

(*99*) 1915. Costumbres Mortuarios de los Indios de Chile y otras partes de America. Santiago—Valparaíso.

(*100*) 1928. La alfarería indígena Chilena. Santiago de Chile.

(*101*) 1928a. Las influencias Chinchas en la alfarería de Chile y la Argentina. In *Anales de la Sociedad Científica Argentina*, T. CIV, Buenos Aires.

(*102*) 1928b. La prehistoria Chilena. Santiago de Chile.

(*103*) 1929. Los indios de la Cordillera y la Pampa en el siglo XVI. In *Revista Chilena de Historia y Geografía*, T. LXII, Santiago de Chile.

(*104*) 1929a. La leyenda de los Césares. Su origen y su evolución. In *Revista Chilena de historia y Geografía*, T. LXII, Santiago de Chile.

Leguizamón, Martiniano

(*105*) 1919. Etnografía del Plata. El origen de las boleadoras y el lazo. In *Revista de la Universidad de Buenos Aires*, XLI, Buenos Aires.

Lehmann-Nitsche, R.

(*106*) 1905. Túmulo indígena en las islas del delta del Paraná, estudiado por Luis M. Torres. In *Revista de derecho, historia y letras*, XXVIII, Buenos Aires.

(*107*) 1912. Ulrich Schmidel der erste Geschichtschreiber der La Plata-Länder 1535–1555. München.

(*108*) 1916. Botones labiales y discos auriculares de piedra procedentes de la región norte de la desembocadura del Río Negro (Patagonia septentrional). In *Rev. del Mus. de La Plata*, T. XXIII (2 ser., T. X), Buenos Aires.

(*109*) 1918. Costumbres nacionales. El origen de las boleadoras y del lazo. In *La Unión*, July 30 and August 1, Buenos Aires.

(*110*) 1920. Ursprung und Verbreitung von Losso und Wurfkugeln. In *Zeitschrift des Deutschen Wissenschaftlichen Verein zur Kultur und Landeskunde Argentiniens*, VI Jahrgang, Buenos Aires.

(*111*) 1922. El grupo lingüístico "Het" de la Pampa Argentina. In *Revista del Museo de La Plata*, T. XXVIII, Buenos Aires.

(*112*) 1924. Piedras labradas para el labio y el lóbulo y collares de conchas procedentes de la Patagonia septentrional. In *Comunicaciones del Museo Nacional de Historia Natural de Buenos Aires*, T. II, No. 13. Buenos Aires.

LINNÉ. S.

(*113*) 1925. The technique of South American ceramics. In *Göteborgs Kungl. Vetenskaps– och Vitterhets Samhälles Handlingar*, fjärde följden, Band 29, No. 5, Göteborg.

(*114*) 1929. Darien in the past. In *Göteborgs Kungl. Vetenskaps–och Vitterhets Samhälles Handlingar*, femte följden. Ser. A, Band 1, No. 3. Göteborg.

LISTA, R.

(*115*) 1878. Les cimetières et paraderos Minuanes de la province d'Entre Rios. In *Revue d'Anthropologie*, T. I–III, Paris.

LOOSER, WALTER

(*116*) 1927. Araucanian textiles. In *Chile*, January–February, New York.

LÓPEZ DE SOUZA, PERO

(*117*) 1861. Diario da navegação. In *Rev. Inst. Hist. Geogr. e Ethn. do Brazil*, XXIV, Rio de Janeiro.

LÓPEZ DE VELASCO, JUAN

(*118*) 1894. Geografía y descripción universal de las Indias. Madrid.

LOTHROP, S. K.

(*119*) 1925. The Thea Heye–La Plata expedition. In *Indian Notes*, II, No. 4, New York.

(*120*) 1925a. Waterways of the Argentine. In *The Independent*, Oct. 17, Boston.

(*121*) 1926. Pottery of Costa Rica and Nicaragua. In *Contr. Mus. Amer. Ind., Heye Fdn.*, VIII, New York.

(*122*) 1927. The Museum Central American Expedition, 1925-1926. In *Indian Notes*, IV, No. 1, New York.

(*123*) 1928. The Indians of Tierra del Fuego. In *Contr. Mus. Amer. Ind., Heye Fdn.*, X, New York.

(*124*) 1929. Polychrome guanaco robes of Patagonia. In *Contr. Mus. Amer. Ind.. Heye Fdn.*, VII, No. 6, New York.

LOZANO, PEDRO

(*125*) 1874. Historia de la conquista del Paraguay Rio de la Plata y Tucuman. 5 vols. Buenos Aires.

MADERO, E.

(*126*) 1892. Historia del puerto de Buenos Aires. Buenos Aires.

Márquez Miranda, Fernando
(*127*) 1930. La navegación primitiva y las canoas monoxilas. In *XXIII Intern. Cong. Amer.*, pp. 736–746, New York.

Martínez, B. T.
(*128*) 1898. Etnografía del Río de la Plata. Los Charrúas. In *Revista Nacional*, XXIV, Buenos Aires.
(*129*) 1900–01. Historia de la provincia de Entre Ríos. Buenos Aires.
(*130*) 1901. Etnografía del Río de la Plata. In *Bol. Inst. Geogr. Arg.*, XXII, Buenos Aires.

Mayntzhusen, F. C.
(*131*) 1912. Ueber vorkolumbianische Siedelungen und Urnenfriedhöfe der Guaraní am Alto Paraná. In *XVII Intern. Congr. Amer.*, Buenos Aires.

Medina, José Toribio
(*132*) 1882. Los aboríjenes de Chile. Santiago.
(*133*) 1897. Juan Díaz de Solis. 2 vols. Santiago de Chile.
(*134*) 1908. El Veneciano Sebastián Caboto al servicio de España. 2 vols. Santiago de Chile.
(*135*) 1908a. Los viajes de Diego García de Moguer al Río de la Plata. Santiago de Chile.

Meillet, A., *and* Cohen, Marcel
(*136*) 1924. Les langues du monde par une group des linguistes sous la direction de A. Meillet et Marcel Cohen. Paris.

Métraux, A.
(*137*) 1927. Migrations historiques des Tupi–Guaraní. In *Journal de la Société des Américanistes de Paris*, N. S., T. XIX. Paris.
(*138*) 1928. La civilisation matérielle des tribus Tupi–Guaraní. Paris.

Montalvo, Hernándo de
(*139*) 1897. Carta dirigida á C. C. R. M. el 23 de Agosto de 1587. In Outes, 1897, pp. 44–45. In Ruiz Guiñazú, 1915, pp. 79–82.

Moore, Clarence B.
(*140*) 1910. Urn-burial. In Handbook of American Indians, *Bull. 30, Bur. Amer. Ethnol.*, pt. 2, p. 873, Washington.

Moreno, F. P.
(*141*) 1874. Noticias sobre antigüedades de los indios del tiempo anterior á la conquista. In *Bol. Acad. de Ccncias de Cordoba.* I, Córdoba.

Morong, Thomas
(*142*) 1892. The Rio de la Plata–its basin, geography and inhabitants. In *Bull. Amer. Geogr. Soc.*, XXIV, New York.

Moussy, Martin de.
(*143*) 1865. Coup d'œil sur l'histoire du bassin de la Plata avant la découverte. In *Revue Américaine*, 2 ser., T. II, Paris.

MURATORI, L. A.
(*144*) 1759. A relation of the missions of Paraguay. Wrote originally in Italian, and now done into English from the French translation. London.

MUSTERS, G. C.
(*145*) 1871. At home with the Patagonians. London.

NAVARRETE, MARTIN FERNÁNDEZ DE.
(*146*) 1851. Biblioteca maritíma española. 2 vols. Madrid.

NORDENSKIÖLD, ERLAND
(*147*) 1903. Präcolumbische Wohn-und Begräbnisplätze an der Sudwestgrenze von Chaco. In *Kögl. Svenska Vetenskaps-Akad. Handlingar*, Bandet 36, No. 7, Stockholm.
(*148*) 1912. Indianerleben. Leipzig.
(*149*) 1919. An ethno-geographical analysis of the material culture of two Indian tribes in the Gran Chaco. In *Comparative Ethnographical Studies*, I, Göteborg.
(*150*) 1920. The changes in the material culture of two Indian tribes under the influence of new surroundings. In *Comparative Ethnographical Studies*. II, Göteborg.
(*151*) 1924. The ethnography of South-America seen from Mojos in Bolivia. In *Comparative Ethnographical Studies*, III, Göteborg.
(*152*) 1924a. Des flèches a trois plumes d'empenne en Amérique du Sud. In *Journal de la Société des Américanistes de Paris*, N. S., T. XVI, Paris.
(*153*) 1925. Au sujet de quelques pointes, dites de harpons, provenant du delta du Paraná. In *Journal de la Société des Américanistes de Paris*, N. S., T. XVII, Paris.

NÚÑEZ CABEZA DE VAÇA, ALVAR
(*154*) 1906. Relación de los naufragios y comentarios. In *Colección de libros y documentos referentes á la historia de América*, V, VI, Madrid.

OLIVEIRA CÉSAR, F. DE.
(*155*) 1895. Datos arqueológicos. Proximidad de Buenos Aires. In *Bol. Inst. Geogr. Arg.*, XVI, Buenos Aires.

ORBIGNY, A. D'
(*156*) 1839. L'homme américain. 2 vols. Paris.
(*157*) 1842. Voyages dans l'Amérique Méridionale. 2 vols. Paris.

OTTSEN, HENDRIK
(*158*) 1905. Viaje de un buque holandés al Río de la Plata. In *Anales de la Biblioteca*, T. IV, Buenos Aires.

OUTES, F. F.
(*159*) 1897. Los Querandíes. Buenos Aires.
(*160*) 1899. Estudios etnográficos. Primera Serie. Buenos Aires.

(*161*) 1902. El primer establecimiento español en el territorio argentina (1527–1902). Noticia histórico-geográfica. In *Anales de la Sociedad científica Argentina*, LIV, Buenos Aires.

(*162*) 1903. Don Juan de Garay. Circunstancias que rodearon su muerte. Estudio histórico-geográfico. In *Estudios*, V, Buenos Aires.

(*163*) 1903a. El Puerto de los Patos y la geografía de la región adyacente en la época de la Conquista. In *Historia*, Vol. I, Buenos Aires.

(*164*) 1904. La Alfarería indígena de Patagonia. In *Anales del Museo Nacional de Buenos Aires*, T. XI (3ª ser., T. IV), Buenos Aires.

(*164*a) 1905. La edad de la piedra en Patagonia. In *Anales del Museo Nacional de Buenos Aires*, T. XII (3ª ser., T. VI), Buenos Aires.

(*165*) 1905a. Sobre un instrumento paleolítico de Luján. In *Anales del Museo Nacional de Buenos Aires*, T. XIII (3ª ser., T. VI), Buenos Aires.

(*166*) 1906. Instrumentos y armas neolíticos de Cochicó. In *Anales del Museo Nacional de Buenos Aires*, T. XIII (3ª ser., T. VI), Buenos Aires.

(*167*) 1909. Observaciones sobre la complicación y sinostosis de las suturas del cráneo cerebral de los primitivos habitantes del sur de Entre Ríos. In *Anales de la Sociedad Científica Argentina*, T. LXVI, Buenos Aires.

(*168*) 1911. Variaciones y anomalías anátomo–antropológicas en los huesos del cráneo de los primitivos habitantes del sur de Entre Ríos. In *Rev. del Mus. de La Plata*, T. XVIII (2ª ser., T. V), Buenos Aires.

(*169*) 1912. Cráneos indígenas del departmento de Gualeguaychú (Provincia de Entre Ríos). In *Anales de la Sociedad Científica Argentina*, T. LXXIII, Buenos Aires.

(*170*) 1913. Sobre las lenguas indígenas rioplatenses. In *Revista de la Universidad de Buenos Aires*, XXIV, Buenos Aires.

(*171*) 1917. Notas para el estudio de la geografía histórica rioplatense. La Matanza y el río de los Querandíes. Buenos Aires.

(*172*) 1917a. El primer hallazgo arqueológico en la isla de Martín García. In *Anales de la Sociedad Científica Argentina*, T. LXXXII, Buenos Aires.

(*173*) 1917b. Valor del hallazgo de una pipa de piedra tallada en la Provincia de Entre Ríos. In *Anales de la Sociedad Científica Argentina*, T. LXXXII, Buenos Aires.

(*174*) 1918. Nuevo jalón septentrional en la dispersión de representaciones plásticas de la cuenca paranaense y su valor indicador. In *Anales de la Sociedad Científica Argentina*, T. LXXXV, Buenos Aires.

(*175*) 1918a. Nuevos rastros de la cultura Guaraní en la cuenca del Paraná inferior. In *Anales de la Sociedad Científica Argentina*, T. LXXXV, Buenos Aires.

(*176*) 1922. Nota informativa del tomo I de los *Escritos de don Antonio Larrañaga*. In *Boletín del Instituto de investigaciones his-*

tóricas (de la Facultad de Filosofía y Letras), Tomo I, Buenos Aires.
(*177*) 1923. Las representaciones plásticas de la cuenca paranaense. In *Revista de la Universidad de Buenos Aires*, T. LI, Buenos Aires.
(*178*) 1926. Algunos datos sobre la arqueología de la Provincia de San Luis. In *Physis*. T. VIII, Buenos Aires.

OVALLE, ALONSO DE
(*179*) 1888. Histórica relación del Reino de Chile. In *Historiadores de Chile*, T. XII, XIII, Santiago de Chile.

OVIEDO Y VALDÉS, G. FERNÁNDEZ DE
(*180*) 1851–55. Historia general y natural de las Indias, islas y tierra-firme del Mar Océano. 4 vols. Madrid.

PAGE. THOMAS J.
(*181*) 1859. La Plata and the Argentine confederation, and Paraguay. Being a narrative of the exploration of the tributaries of the River La Plata and the adjacent countries during the years 1853, '54, '55, and '56, under the orders of the United States Government. New York.

PALAVECINI, ENRIQUE
(*182*) 1930. Tipos de tienda usados por los aborigenes sudamericanos. In *XXIII Intern. Congr. Amer.*, New York.

PELLIZA, MARIANO A.
(*183*) 1888. Historia Argentina. Buenos Aires.

PERNETTY, J. A.
(*184*) 1770. Histoire d'un voyage aux Isles Malouines. 2 vols. Paris.

PREUSS, K. T.
(*185*) 1929. Monumentale vorgeschichtliche Kunst. 3 vols. Göttingen.

PRINCE, CARLOS
(*186*) 1905. Idiomas y dialectos indígenas del continente Hispano Sud-Americano. Lima.

PRITCHARD, J. C.
(*187*) 1843. Histoire naturelle de l'homme. Paris.

QUESADA, VICENTE G.
(*188*) 1903. Los Indios en las provincias del Río de la Plata. In *Historia*, Vol. I, Buenos Aires.

RAMÍREZ, LUIS
(*189*) 1897. Carta á su padre—Puerto de San Salvador, 10 de Julio de 1528. In Outes, 1897, Appendix 5. Also in Medina, 1908. Also in Archivo colonial. Also in Madeiro.

RELACIONES DE PROBANZAS
(*190*) 1903. Relaciones de probanzas en el pleito entre el capitán Fransisco de Rojas y Sebastián Caboto. In *Historia*. I, Buenos Aires.

REPARTAMIENTO
(*191*) 1897. Repartamiento de indios de esta cuidad (Buenos Aires), hecho por el general Juan de Garay. In Outes, 1897, Appendix 3. Facsimile in Ruiz Guiñazú, 1915, pp. 92–97.

REVELLO DE TORRE, JOSÉ
(*192*) 1929. Documentos referentes a la Argentina en la Biblioteca Nacional y en el Depósito Hidrográfico de Madrid. *Publicaciones del Instituto de investigaciones Históricas*, No. XLIII, Buenos Aires.

RIVET, P.
(*193*) 1924. Langes Américaines. In Meillet and Cohen, 1924.

RIVET, P. *and* VERNEAU, R.
(*194*) 1912. Ethnographie ancienne de l'Équateur. In *Mission du Service Geographique de l'armée pour la mesure d'un arc de méridien équatorial en Amérique du Sud*, T. VI, Paris.

ROSALES, DIEGO DE
(*195*) 1877. Historia general del Reino de Chile, 3 Vols. Valparaiso.

RUIZ, P. ANTONIO
(*196*) 1639. Conquista espiritual hecha por los religiosos de la compañia de Jesús en las provincias del Paraguay, Paraná, Uruguay y Tape. Madrid.

RUIZ GUIÑAZÚ, ENRIQUE
(*197*) 1915. Garay fundador de Buenos Aires. Documentos referentes á las fundaciones de Santa Fe y Buenos Aires, publicados por la municipalidad de la capital federal. Buenos Aires.

A RUTTIER
(*198*) 1904. A ruttier which declareth the situation of the coast of Brasil from the isle of Santa Catelina unto the mouth of the river of Plata, and all along up within the sayd river. . . In Hakluyt, 1904, XI, pp. 96–101.

SÁNCHEZ LABRADOR, P. JOSÉ
(*199*) 1910. El Paraguay católico. 3 vols. Buenos Aires.

SAN MARTÍN, J. Z. DE
(*200*) 1888. Tabaré: indice alfabetico de algunas voces indígenas. Montevideo.

SANTA CRUZ, ALONSO DE
(*201*) 1908. Die Karten von Amerika in dem Islario General . . . herausgegeben von Franz R. v. Wieser. Innsbruck.

SCHMIDEL, ULRICH
(*202*) 1891. A true and agreeable description of some principal Indian lands and islands. . . In *Hakluyt Soc. Publ.*, LXXXI, London.

SCHMIDT, P. W.
(*203*) 1913. Kulturkreise und Kulturschichten in Südamerika. In *Zeitschrift für Ethnologie*, Bd. XLV, heft VI, Berlin.

SCHULLER, R. R.
(*204*) 1904. *See* AZARA, 1904.
(*205*) 1906. Sobre el orijen de los Charrúa. Santiago de Chile.
(*206*) 1917. The only known words of the Charrua language of Rio de la Plata. In *XIX Intern. Congr. Amer.*, Washington.
(*207*) 1919–20. On the "Gandules" or "Chandules" Indians of Argentine. In *Anthropos*, Bd. XIV-XV, San Gabriel–Mödling.

SEPP, ANTONY, *and* BEHME, ANTONY
(*208*) 1732. An account of a voyage from Spain to Paraquaria . . . Translated from the High Dutch Original, printed at Nurenberg, 1697. In Churchill, 1732, IV, pp. 596–622.

SERRANO, ANTONIO
(*209*) 1921. Contribución al conocimiento de la arqueología de los alrededores de Paraná. Paraná.
(*210*) 1922. Algunas puntas de flechas neolíticas de las inmediaciones de Federación (Entre Ríos). In *Prometeo*, T. I. no. 13, Paraná.
(*211*) 1922a. Mapa etnográfico de la provincia de Entre–Ríos. In *Revista Chilena de Historia Natural*, T. XXVII, Santiago de Chile.
(*212*) 1922b. Sobre un nuevo procedimiento en la technica alfarera del litoral. In *Prometeo*, T. I. No. 16, Paraná.
(*213*) 1922c. Sobre un recipiente indígena de Hernandarias, Provincia de Entre–Ríos. In *Prometeo*, T. I, No. 14, Paraná.
(*214*) 1923. Arqueología de Tejas (Provincia de Sante Fé). In *Revista Universitaria del Litoral*, No. 12, Paraná Las.
(*215*) 1923a. Notas para el capitulo introducción de apuntes de etnografía y arqueología de la provincia de Entre Ríos. In *Prometeo*, T. II, Nos. 26–27, Paraná.
(*216*) 1924. Contribución all conocimiento de la industria de la piedra entre los primitivos habitantes de la mesopotamia. In *Rev. Arg. de Ciencias Naturales*, T. I, No. 4. suppl., Paraná.

STEINEN, KARL VON DEN
(*217*) 1894. Unter den Naturvölkern Zentral–Brasiliens. Berlin.

TECHO, NICOLAS DEL
(*218*) 1673. Historia Provinciæ Paraquariæ Societatis Iesu. Leodi.
(*219*) 1732. The History of the Provinces of Paraquay, Tucuman, Rio de la Plata, Parana, Guaira, and Urvaica. And something of the Kingdom of Chile, in South America. In Churchill, 1732, IV, pp. 636–749. [An abridged edition of the above.]

THOUAR, A. D.
(*220*) 1891. Explorations dans l'Amérique du Sud. Paris.

TORRES, L. M.
(*221*) 1903. El cementerio indígena de Mazaruca. In *Historia*, I, Buenos Aires.
(*222*) 1903a. Los cementerios indígenas del sur de la provincia de Entre Ríos. In *Anales del Museo Nacional de Buenos Aires*, XVIII (2d ser., Vol. V), Buenos Aires.

(*223*) 1907. Informe sobre la exploración arqueológica al Delta del Paraná y sur de Entre Ríos. In *Anales de la Sociedad Científica Argentina, LXIV, Buenos Aires.*

(*224*) 1907a. Arqueología de la cuenca del río Paraná. In *Revista del Museo de La Plata*, XIV, Buenos Aires.

(*225*) 1911. Los primitivos habitantes del delta del Paraná. In *Universidad Nacional de La Plata, Biblioteca Centenaria*, IV, Buenos Aires.

(*226*) 1919. Urnas funerarias en la cuenca del Río Rosario. In *Rev. del. Mus. de la Plata*, T. XXV, Buenos Aires.

(*227*) 1922. Arqueología de la península San Blas (Provincia de Buenos Aires). In *Rev. del Mus. de La Plata*, T. XXVI, Buenos Aires.

Torres Lanzas, Pedro

(*228*) 1921. Relación descriptiva de los mapas, planos, etc. del Virreinato de Buenos Aires. In *Facultad de Filosofía y letras, Publicaciones de la sección de historia*, No. VII. Buenos Aires.

Trelles, M. R.

(*229*) 1862. Registro estadístico (1582–1677), I, Buenos Aires.

(*230*) 1864. Estudio sobre el origen de los indios Querandís y etnografía de la comarca occidental de La Plata al tiempo de la conquista. Buenos Aires.

Vaz, López

(*231*) 1904. An extract out of the discourse of one Lopez Vaz a Portugal. In Hakluyt, 1904, XI; pp. 92–95.

Vignati, Milcíades A.

(*232*) 1925. Noticia sobre las islas del Paraná por Fransisco Javier Muñiz. In *Facultad de Filosofía y letras de la Universidad Nacional de Buenos Aires, Publicaciones del Instituto de Investigaciones Geográficas*, No. 9, Buenos Aires.

Villalta, Fransisco de

(*233*) 1903. Carta escrita desde la Asunción del Paraguay en Junio 22 de 1556. In Schmidel, edition of the Junta de historia y numismática americana de Buenos Aires. Buenos Aires.

Xarque, Fransisco

(*234*) 1687. Insignes missioneros de la Compañía de Iesus de la Provincia del Paraguay. Pamplona.

Zeballos, E. S.

(*235*) 1878. Note sur un tumulus préhistorique de Buenos Aires. In *Revue d'Anthropologie*, 2 ser., I, Paris.

(*236*) 1879. Noticias preliminares sobre el hombre primitivo de Buenos Aires. Los Guaraníes. In *Bol. Inst. Geogr. Arg.*, I, Buenos Aires.

(*237*) 1898. Orígines nacionales. Despoblación de Buenos Aires por Irala el 10 de Abril de 1541. In *Bol. Inst. Arg. Geogr.*, XIX, Buenos Aires.

ZEBALLOS, E. S., *and* PICO, P.

(*238*) 1878. Informe sobre el túmulo prehistórico de Campana. In *Anales de la Sociedad Científica Argentina*. VI, Buenos Aires.

ADDENDA

APARICIO, F. DE

(*239*) 1925. Un nuevo documento relativo a la colocación de las asas zoomorfas en la cerámica del litoral paranense. In *Physis*, T. viii, Buenos Aires.

(*240*) 1928. Notas para el estudio de la arqueología del sur de Entre Ríos. In *Anales de la Facultad* de Ciencias de la Educación, T. III, Paraná.

DEBENEDETTI, SALVADOR

(*241*) 1911. Noticia sobre un cementerio indígena de Baradero. In *Facultad de Filosofía y Letras, Publicaciones de la Sección Antropológica*, No. 9, Buenos Aires.

DUFO, POLICARPO

(*242*) 1870. Informe sobre lo sucedido en la entrada que se hizo el año 1715 a los mohanas y yaros. In *Revista del Archivo General de Buenos Aires*, T. II, Buenos Aires.

FARIÑA NÚÑEZ, ELOY

(*243*) 1929. Filiación étnica y linguística de las charrúas. In *La Prensa*, January 10, Buenos Aires.

MÁRQUEZ MIRANDA, FERNANDO

(*244*) 1931. La navegación primitiva y las canoas monoxilas (contribución a su estudio). In *Revista del Museo de La Plata*, T. XXXIII, Buenos Aires.

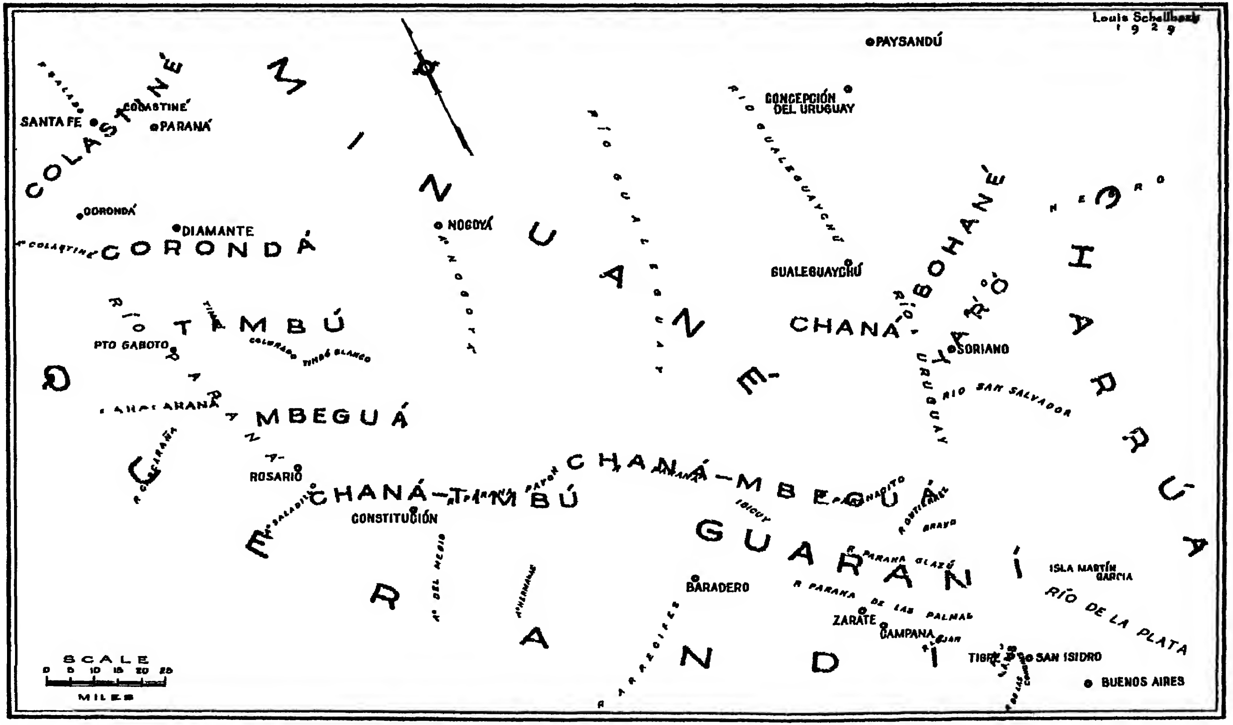
SALLABBERY, J. F.

(*245*) 1926. Los charrúas y Santa Fé. Montevideo.

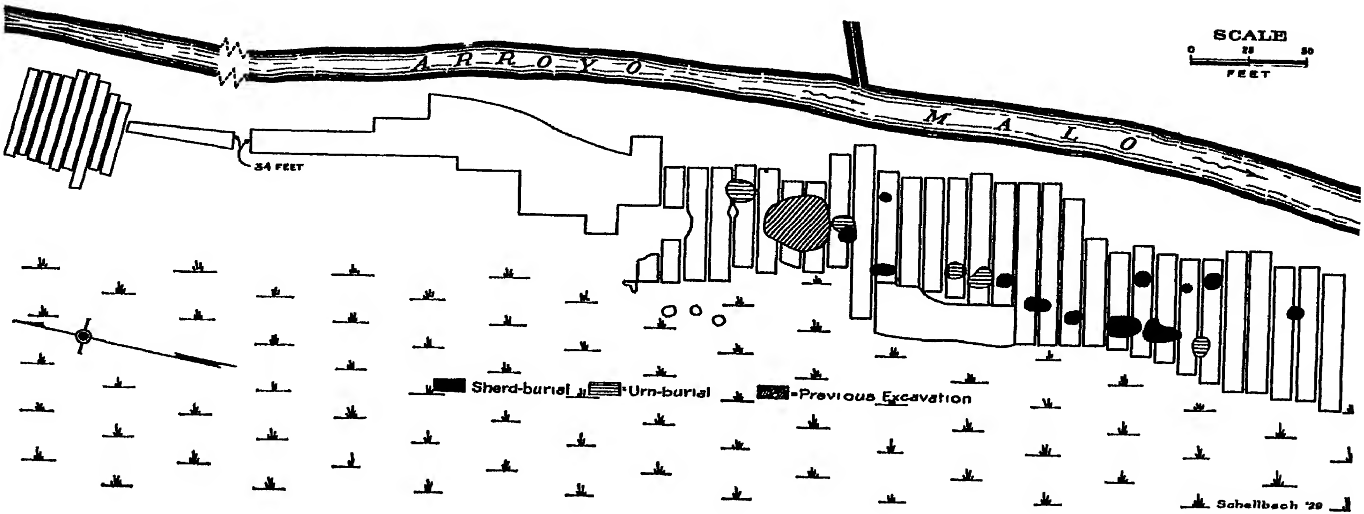
SERRANO, ANTONIO

(*246*) 1928. Sobre algunas piezas de alfarería indígena de la provincia de Entre Ríos, conservadas en el Museo de Paraná. In *Physis*, T. ix, Buenos Aires.

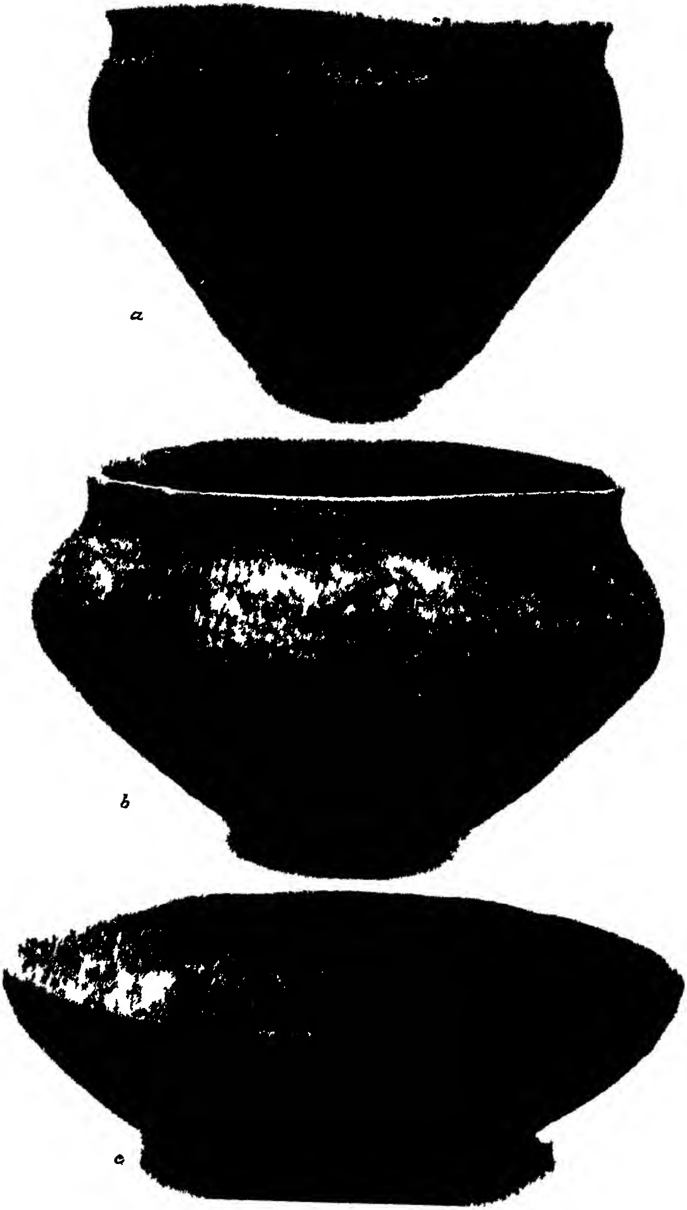
(*247*) 1930. Los primitivas habitantes del territorio Argentino. Buenos Aires.



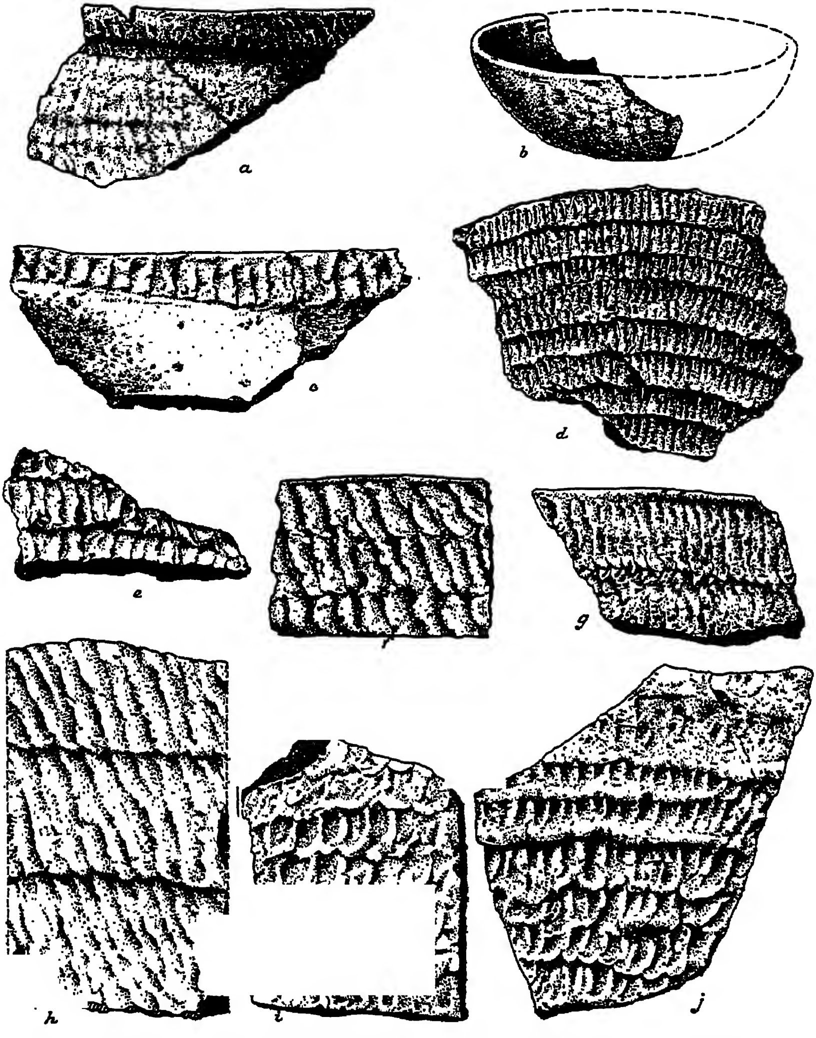
Tribes of the Paraná and R. La Plata as located in the sixteenth century.



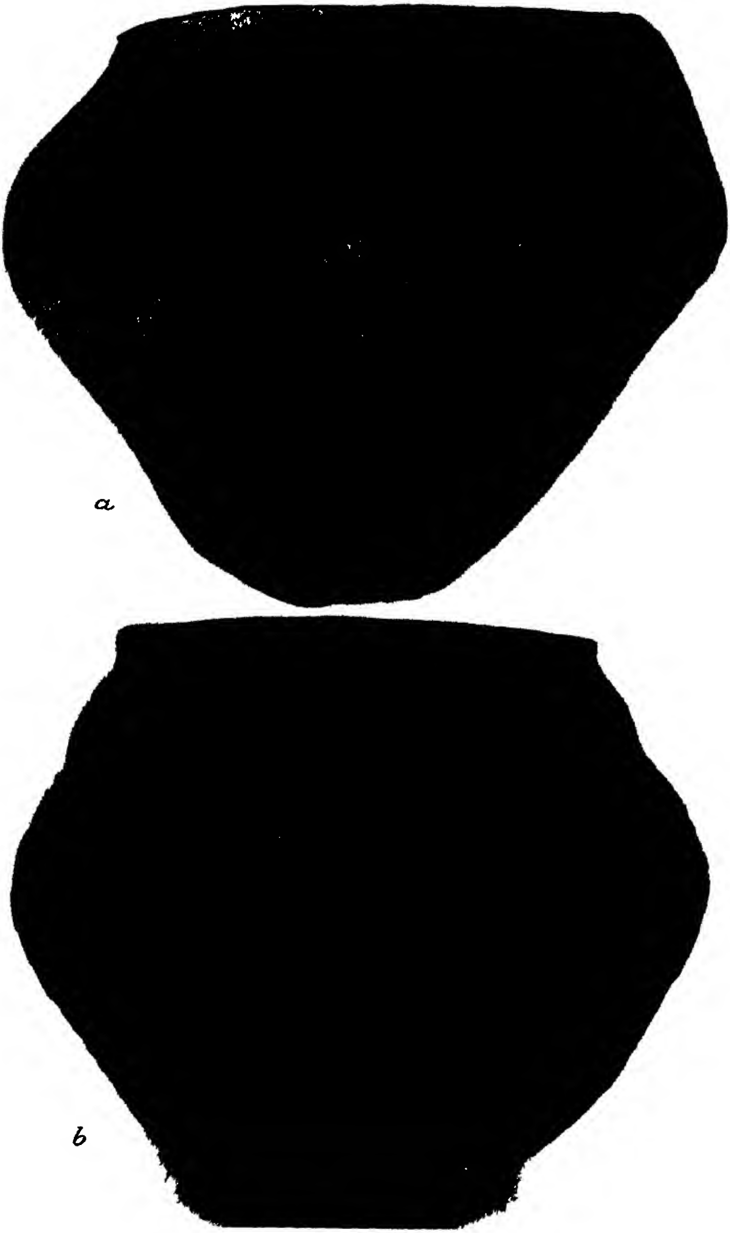
Refuse—heap and burial ground excavated by the Thea Heye–La Plata expedition. Arroyo Malo. Argentina.



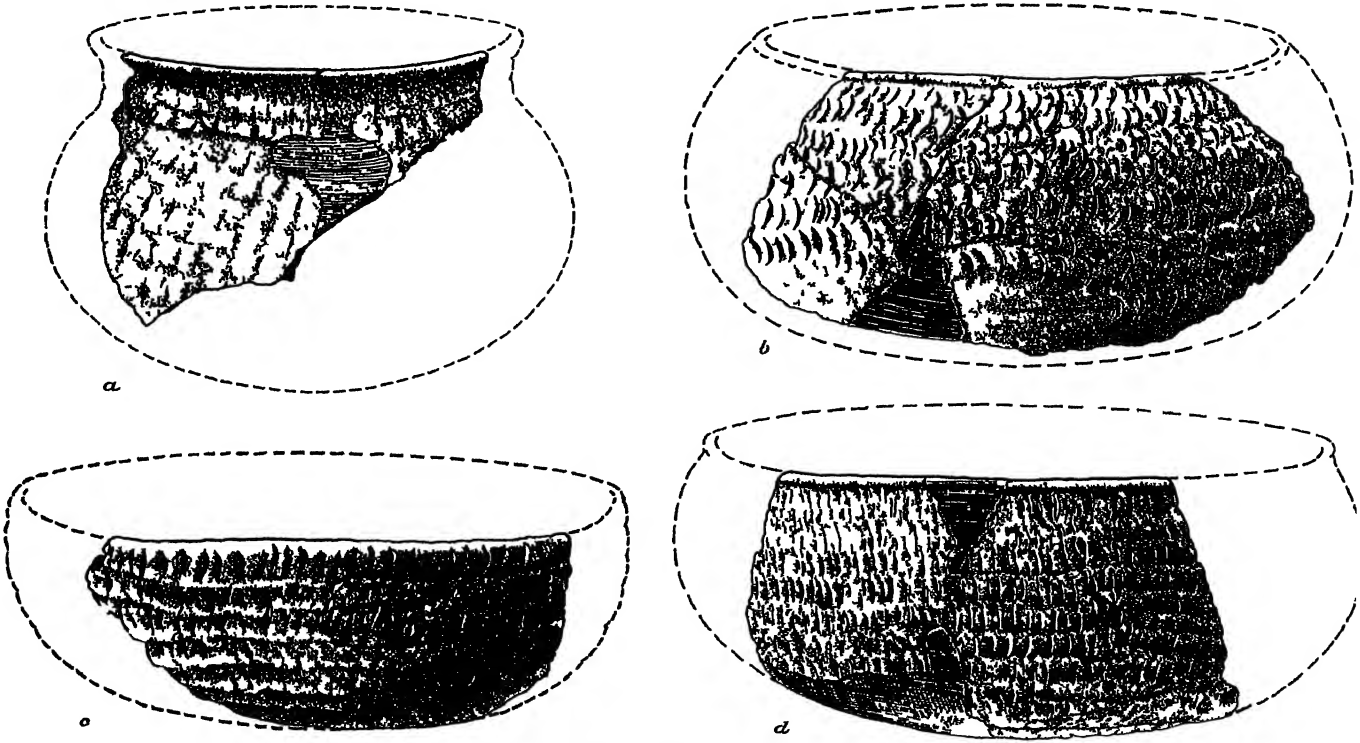
Thumb-marked corrugated vessels. Arroyo Malo. Diam. $13\frac{1}{4}$, $15\frac{1}{4}$, $15\frac{7}{8}$ in. (14/6659, 7103, 6656)



Thumb-marked corrugated sherds. Arroyo Malo. Length of c, 4¼ in. (14/7111)

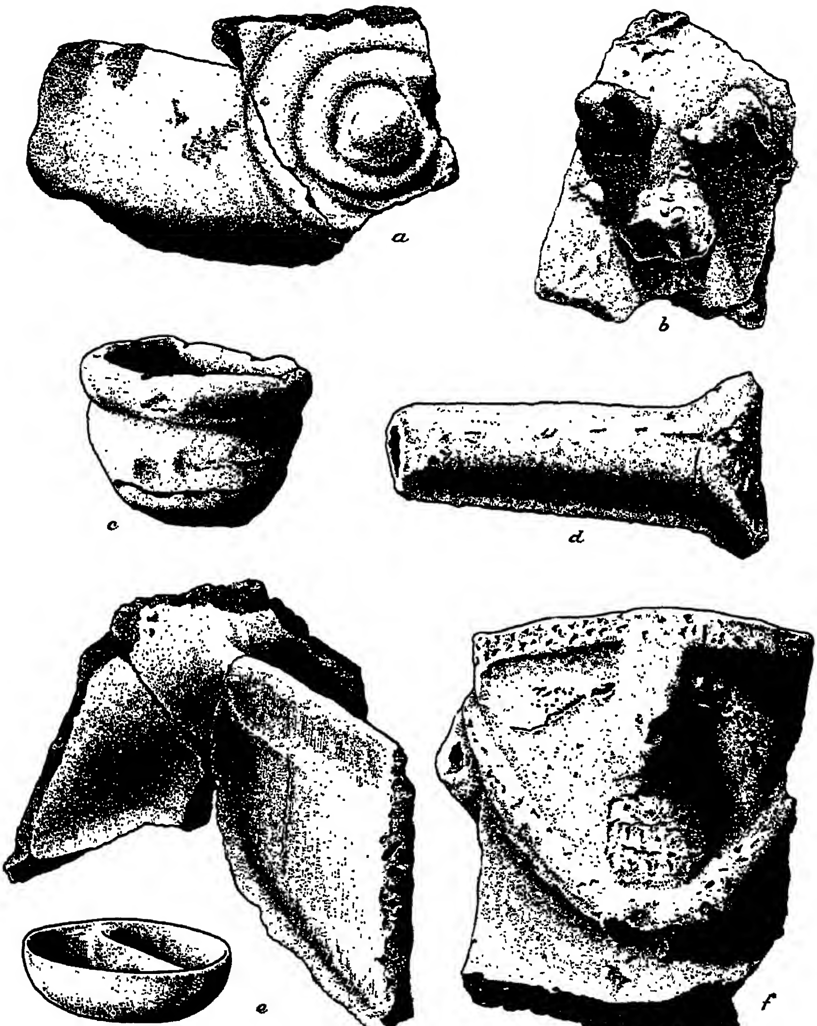


Nail- and thumb-marked jars. Arroyo Malo. Diams., 20¼, 16¾ in. (14/7102, 7104)



Nail marked sherds. Arroyo Malo. Restored diams., 4½ to 5¼ in. (14/7111)

Red–ware bowls Arroyo Malo. Diams., 14, 21, 23 in. (14/6654, 7105, 7105)



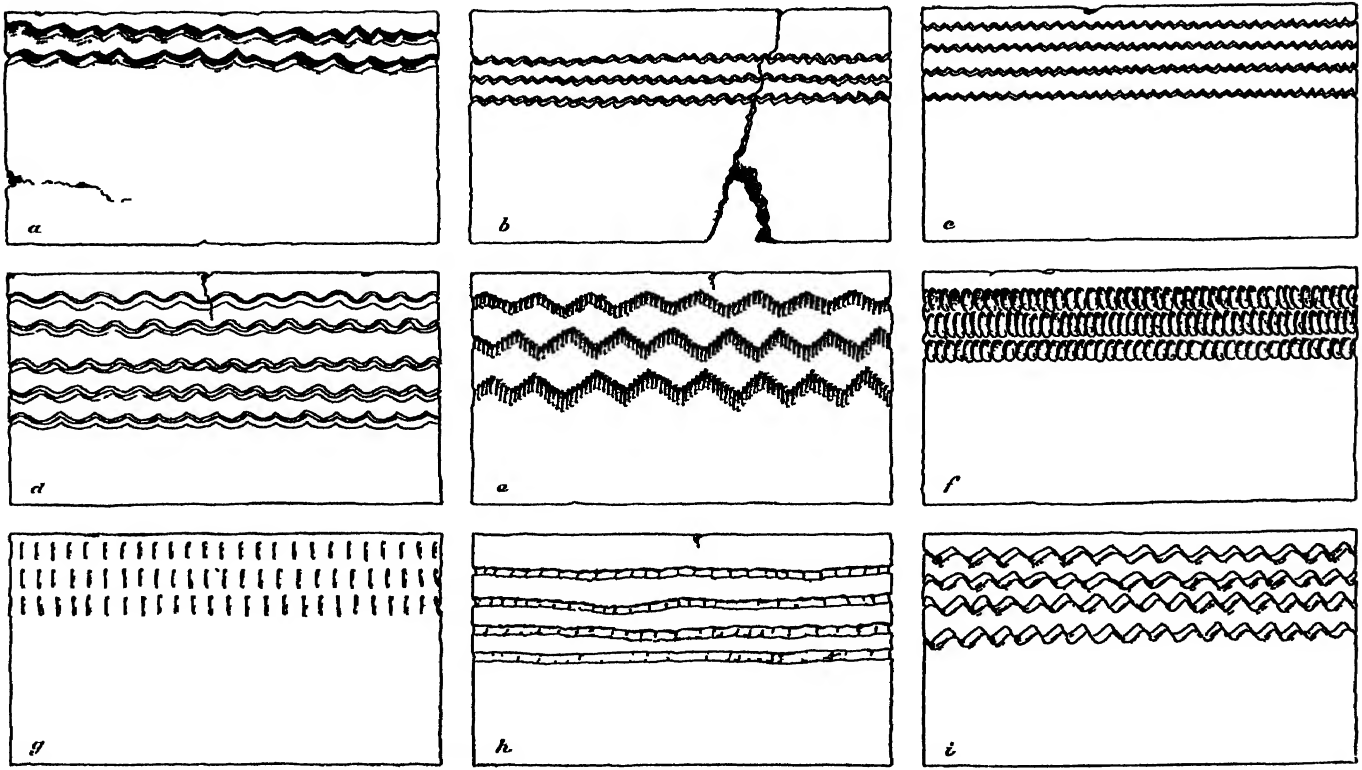
Miscellaneous red-ware types. Arroyo Malo. Length of *a*, 4⅝ in.
(14/6666, 6668, 6661, 6663, 6664, 6665)

Painted vessels. Arroyo Malo. Heights: *a*, 1⅝ in.; *b*, 18 in. (14/6670, 6657)

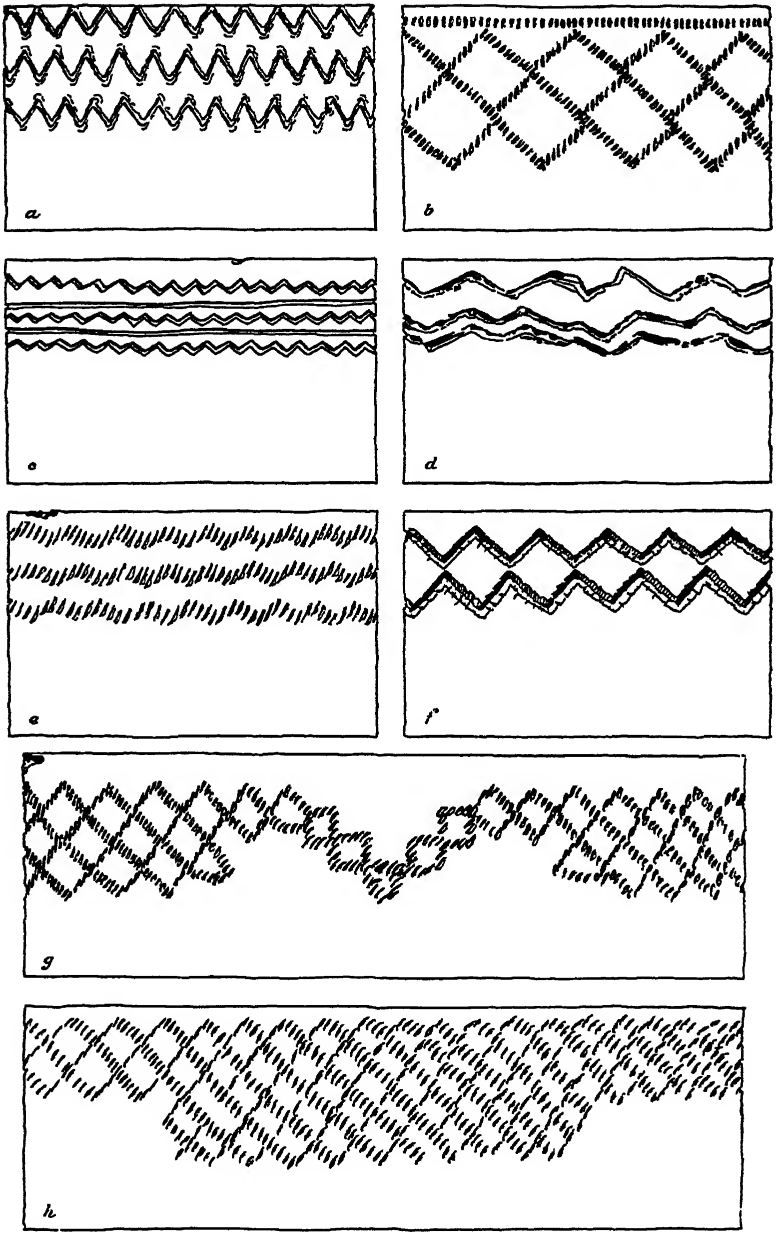
a

b

El Cerrillo before and during excavation



Incised designs. El Cerrillo.



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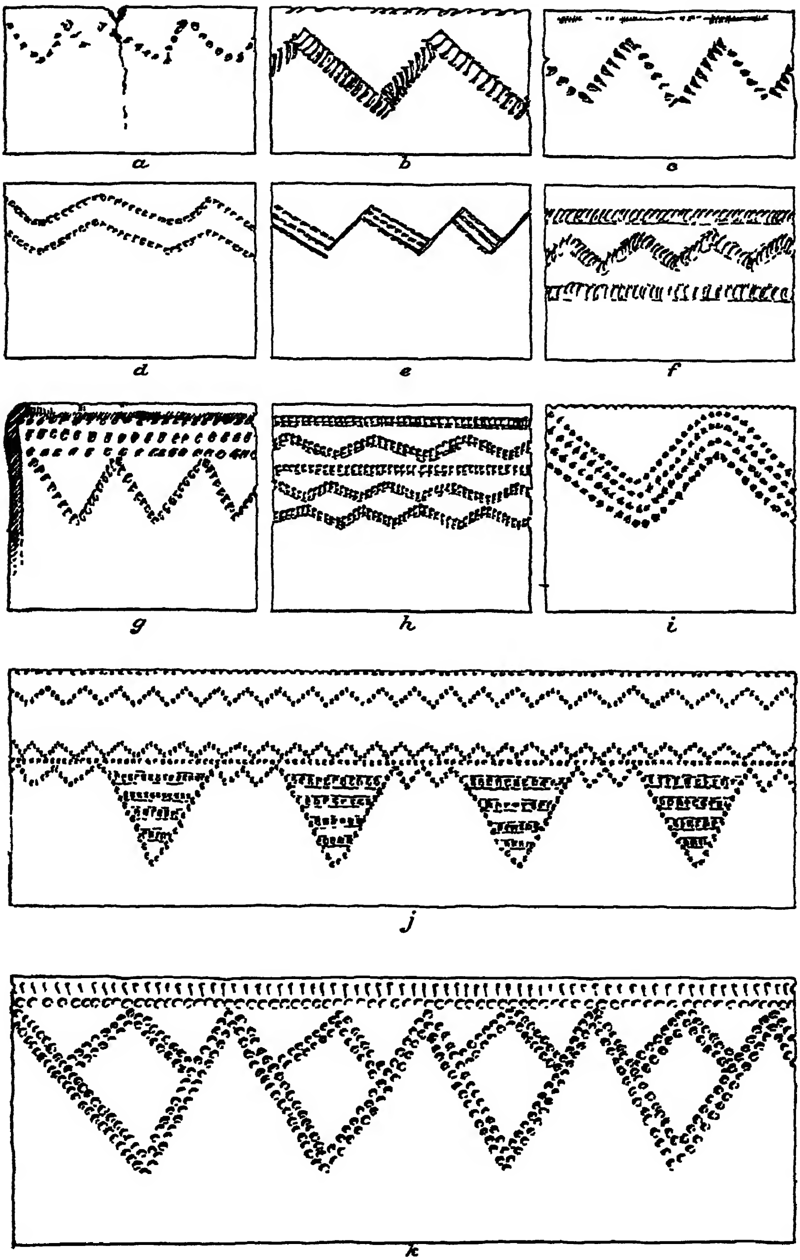

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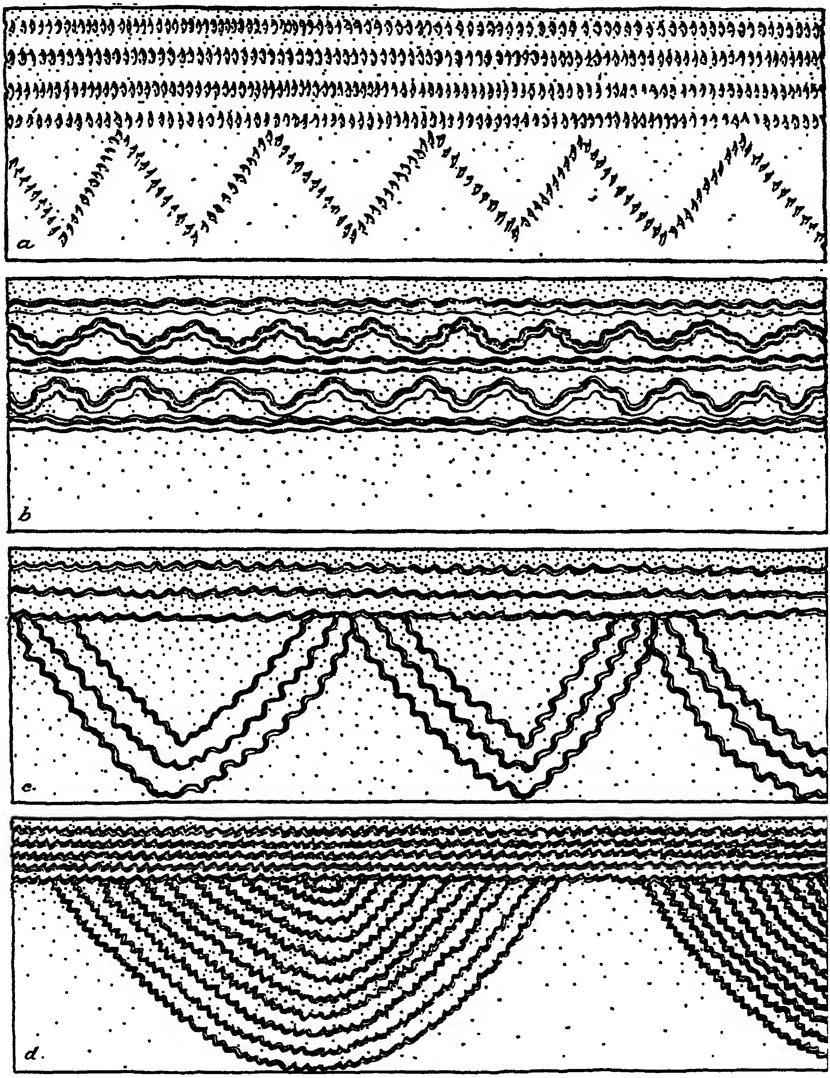

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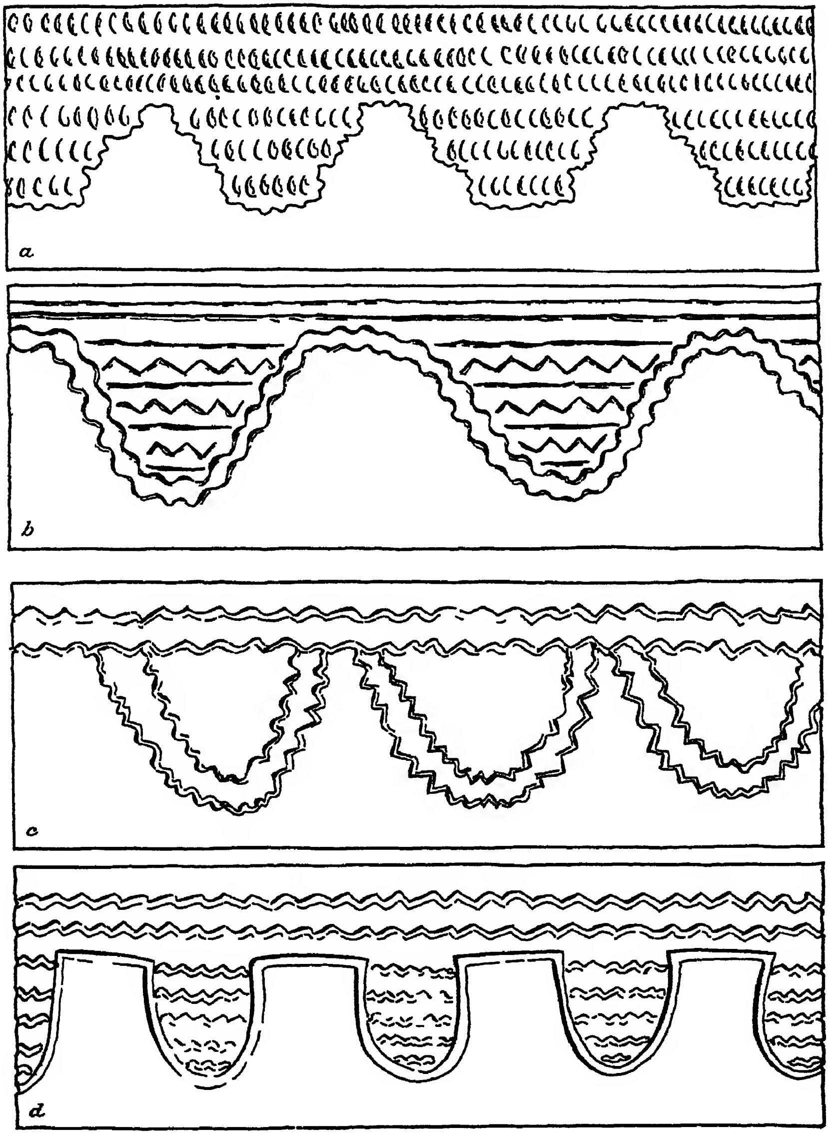

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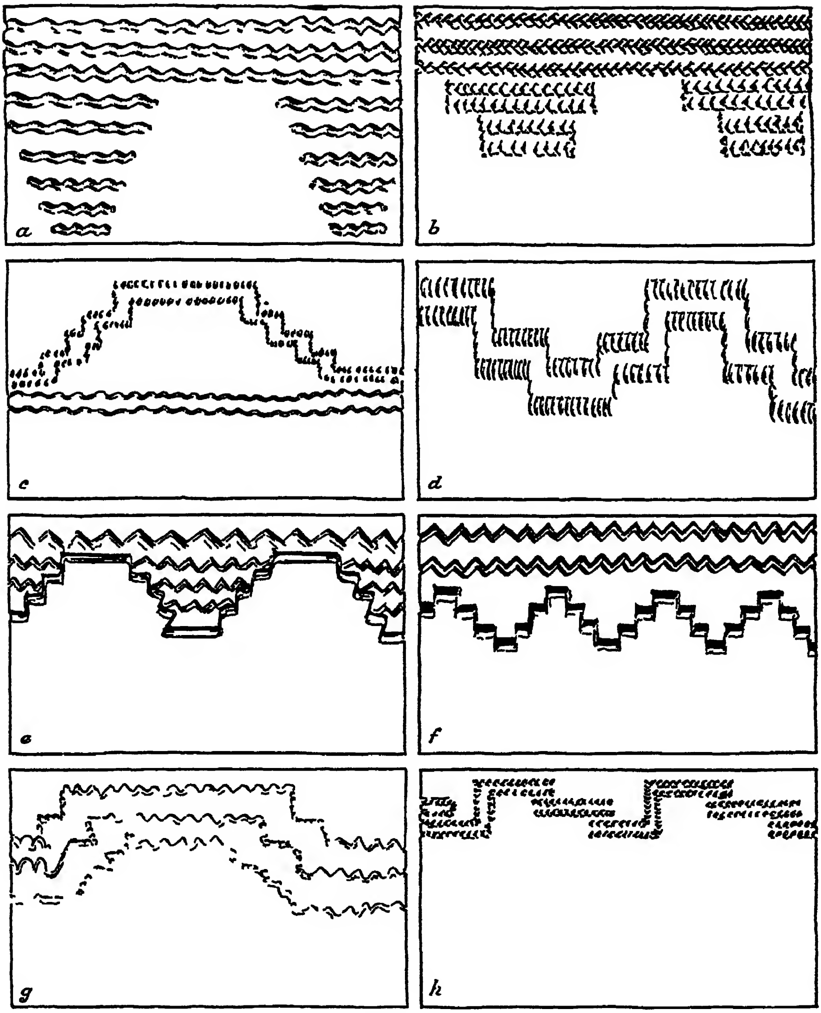

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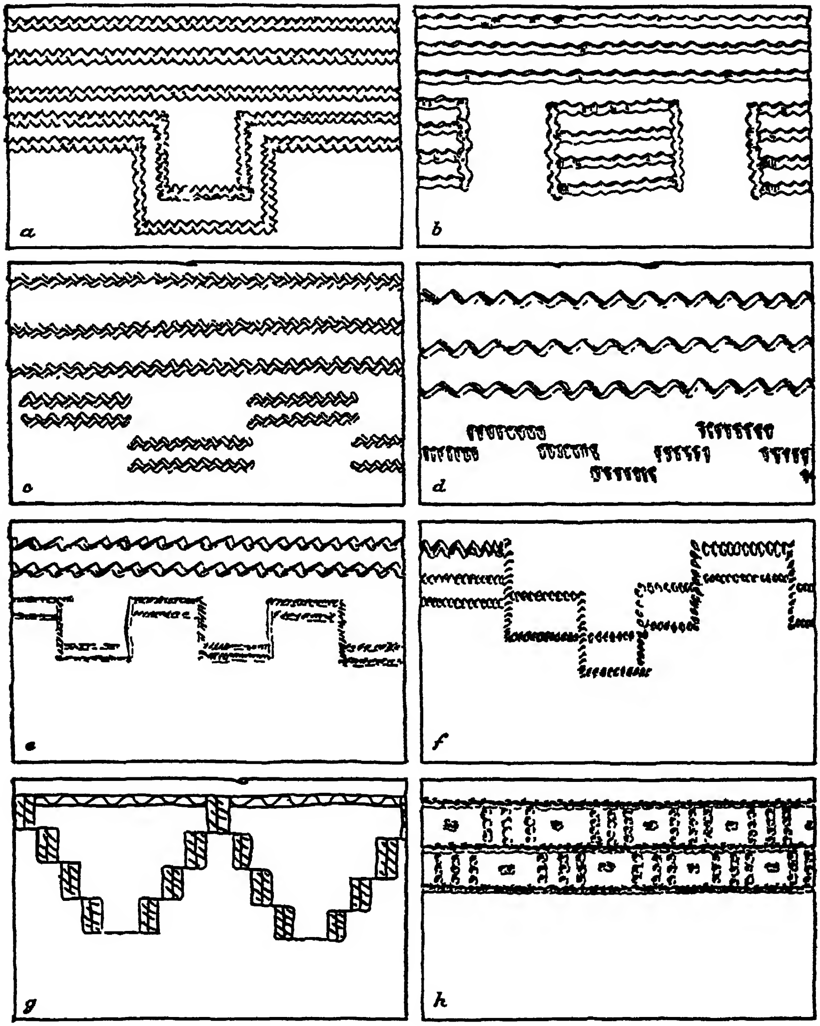

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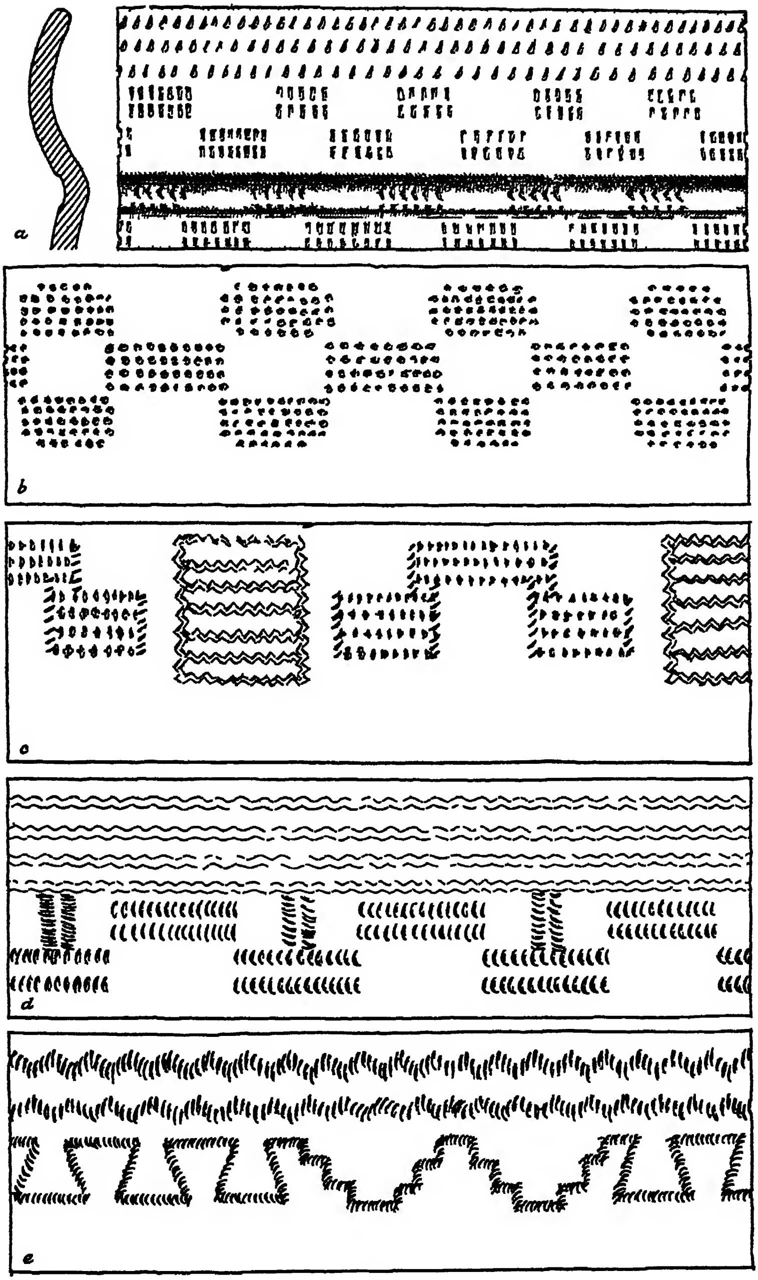
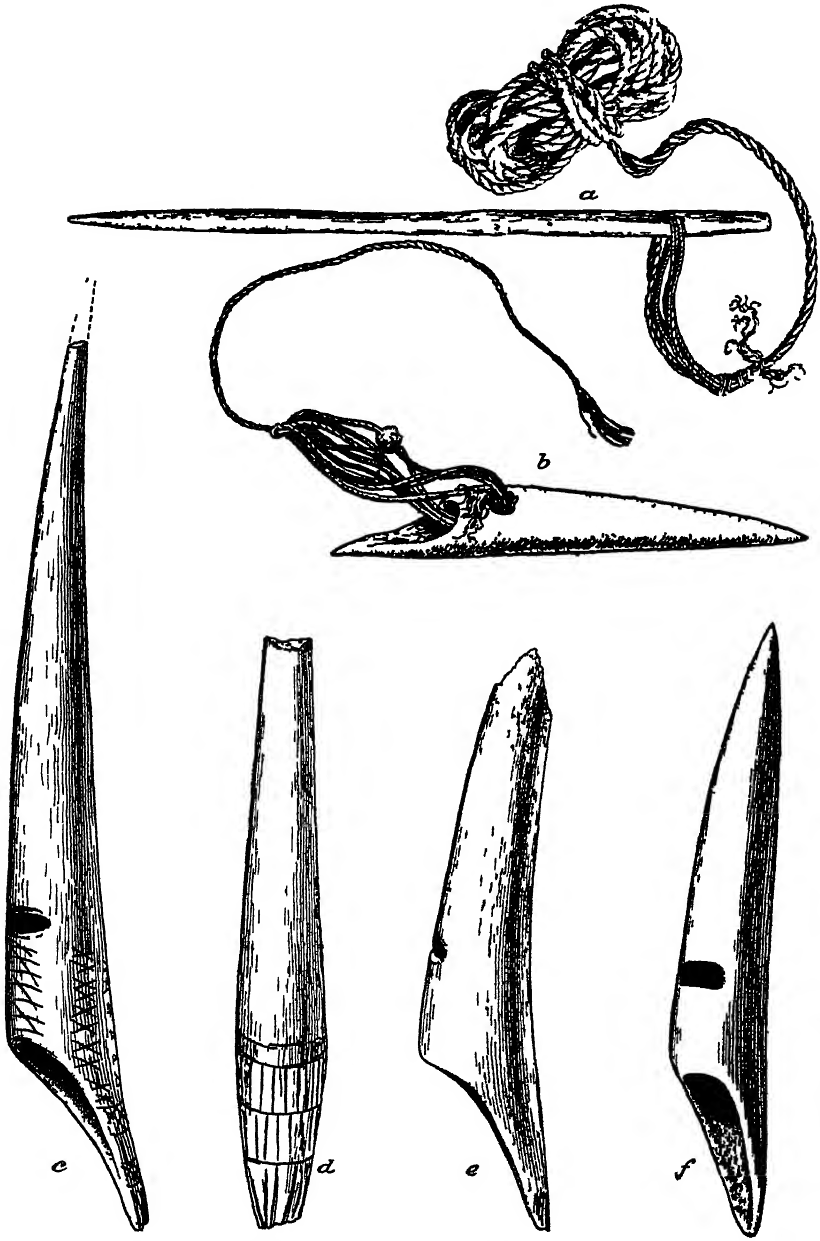
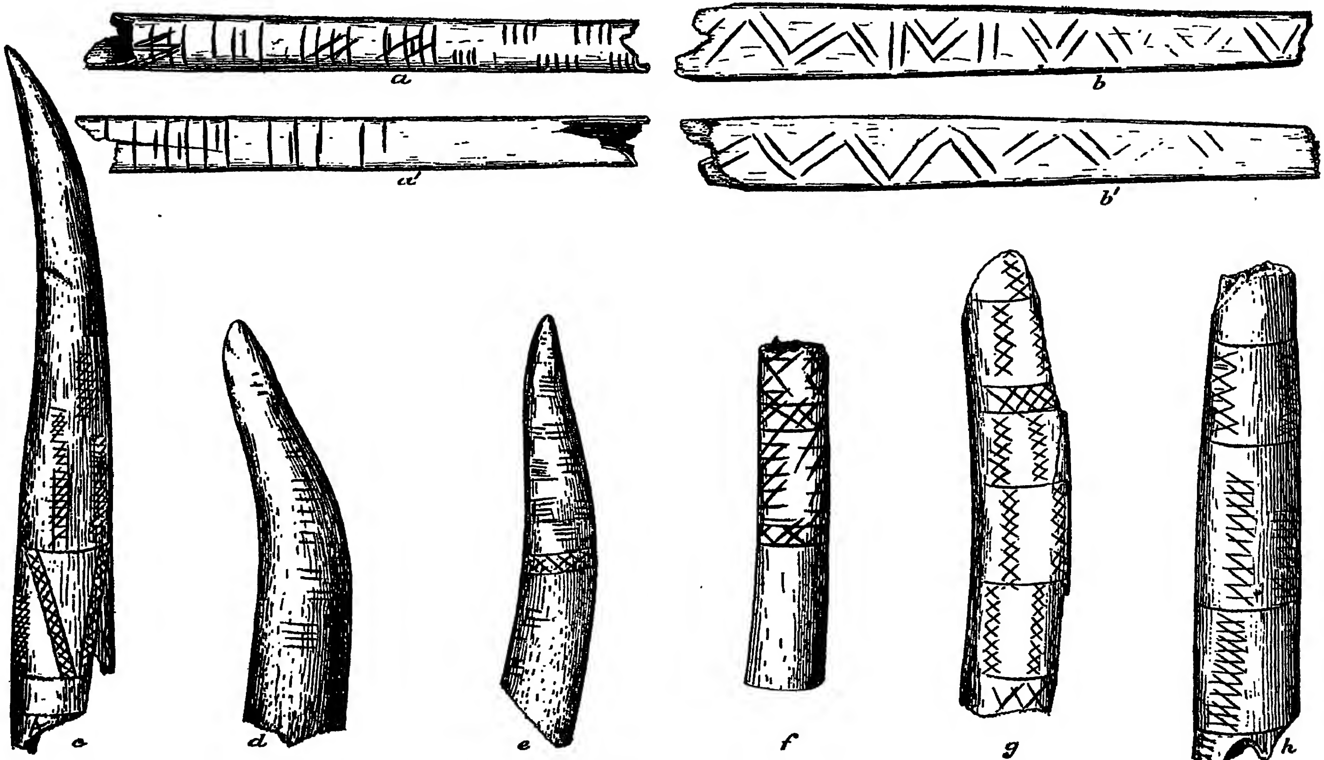


Incised designs. El Cerrillo

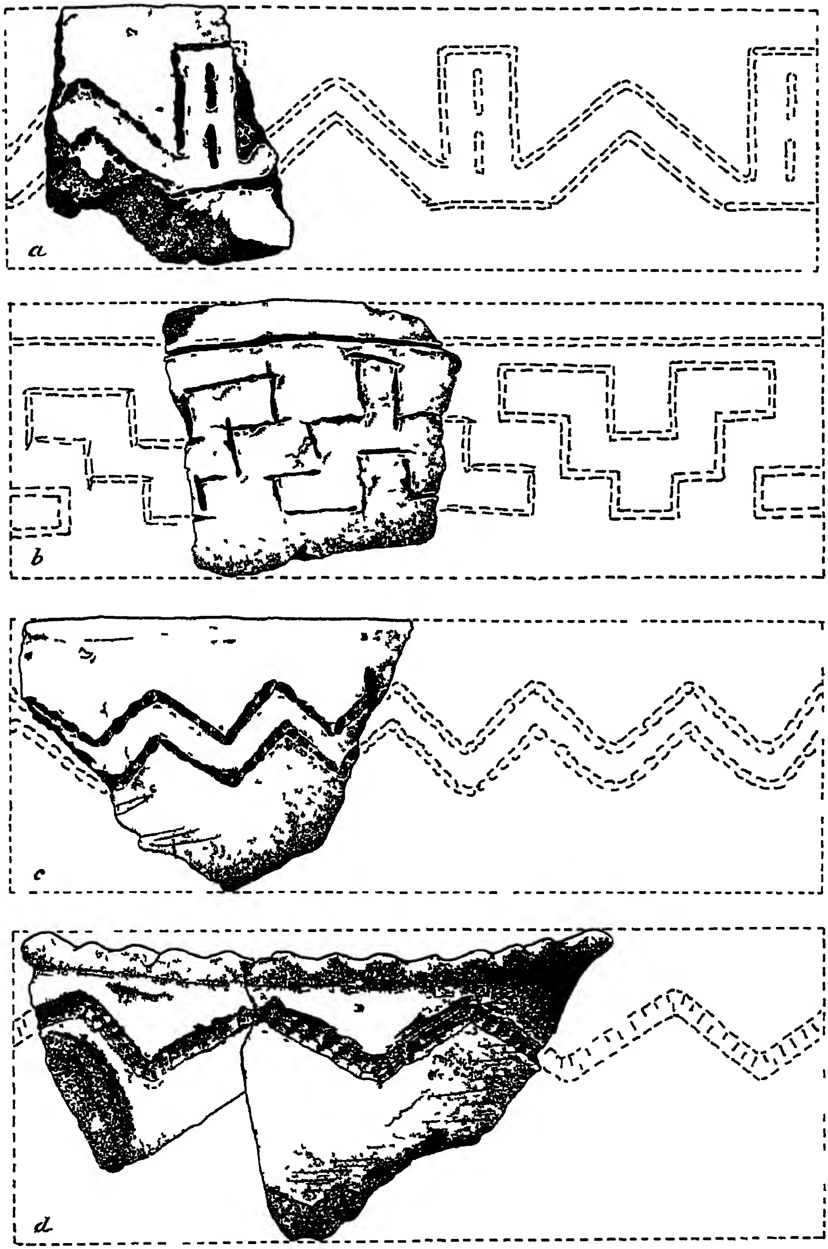
Bone awls and antler blanks, El Cerrillo. Lengths, 1 to 6¾ in. (*a*, 14/4760; *b*, *c*, 4757; *d*, 4790; *e*, 4797; *f*, 4794; *g*, *h*, *m*, 4814; *i*, *j*, 4813; *k*, *l*, 4803)



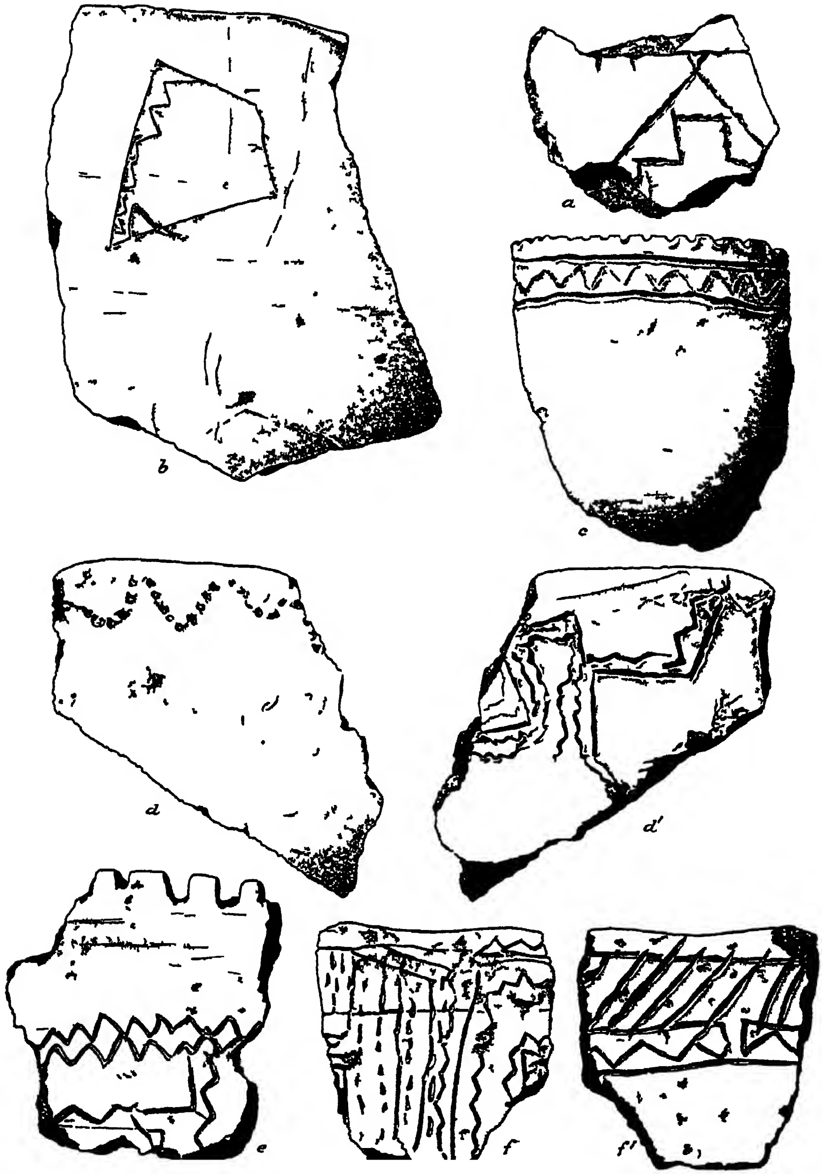
Fish-stringers. *a*, Ashlushlay; length, 10 in. *b*, Mataco; length, 4¾ in. Both after Nordenskiöld (1925). *c, d, e*, El Cerrillo. Lengths, 6¼, 4, 4¼ in. (c, 14–4796; *d, e*, 4795)



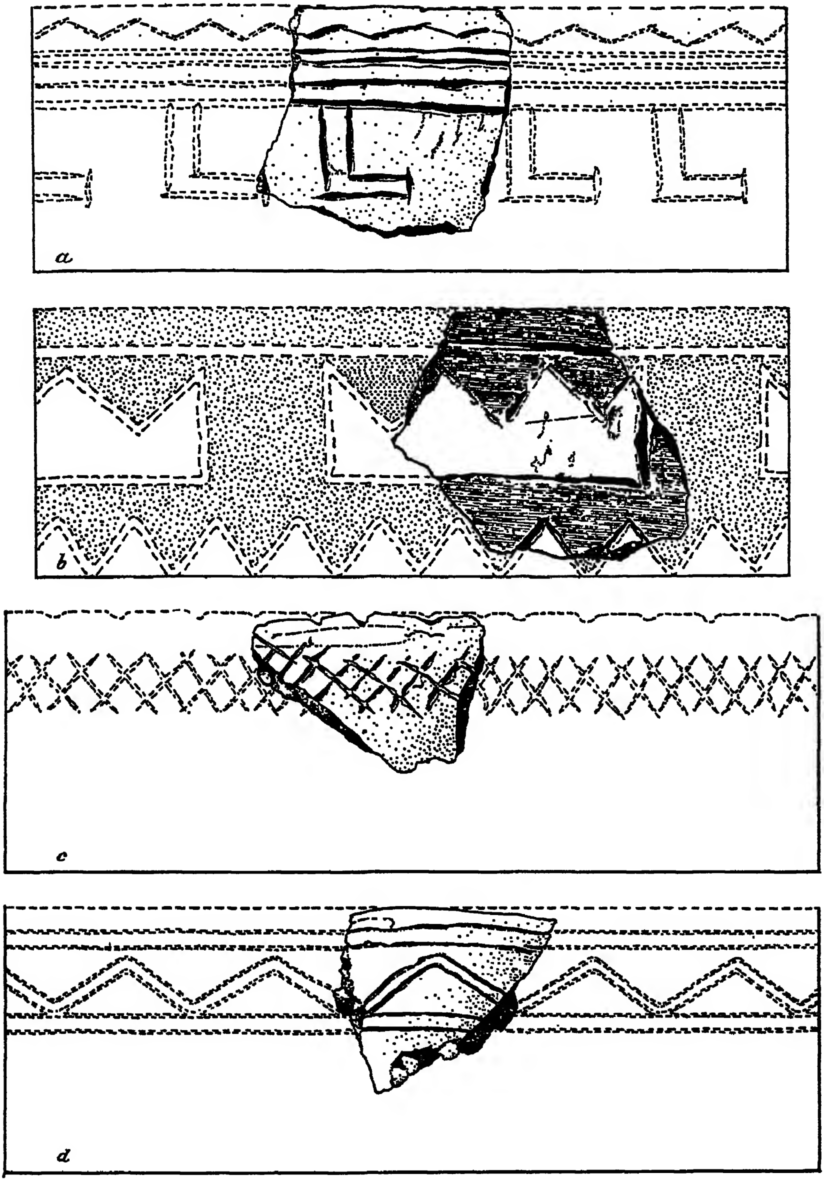
Incised bones and antlers. El Cerrillo. Length of *d*, 3 in. (*a*, *f*, *g*, 14/4807; *b*, 4806; *c*, 4798; *d*, 4801; *c*, 4824; *h*, 4809)



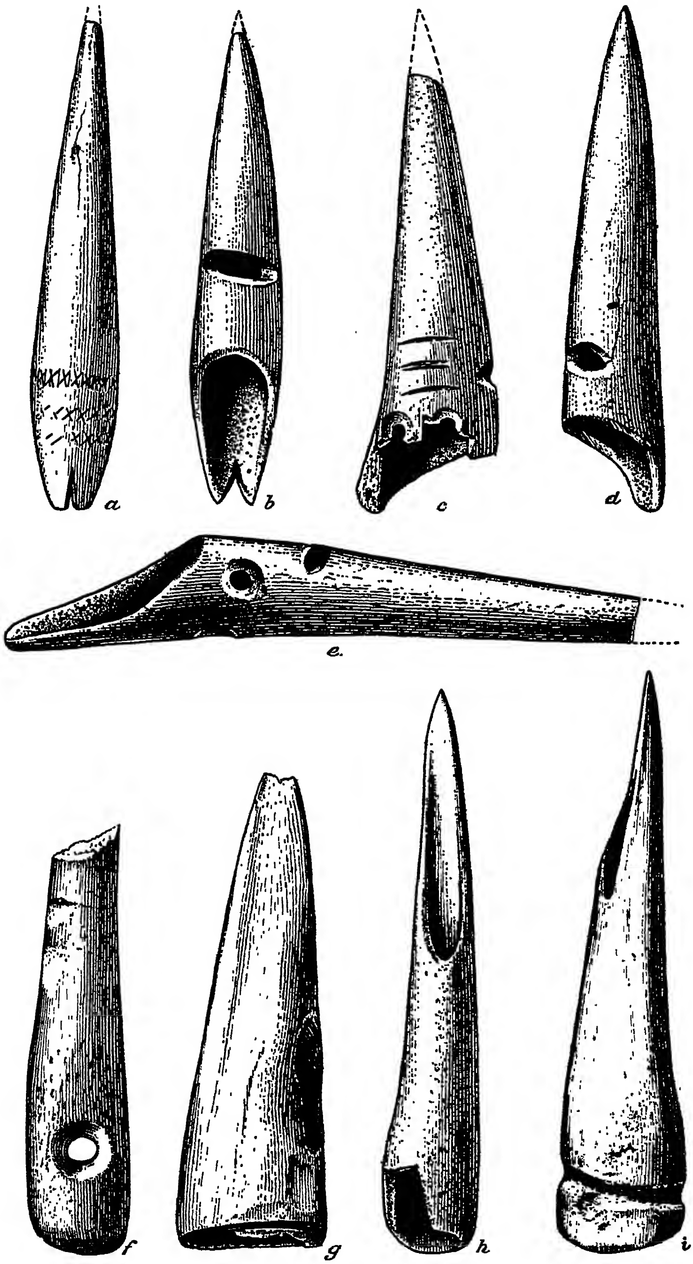
Incised sherds. Arroyo Sarandí. Length of *d*, 4 in. (14/7120)



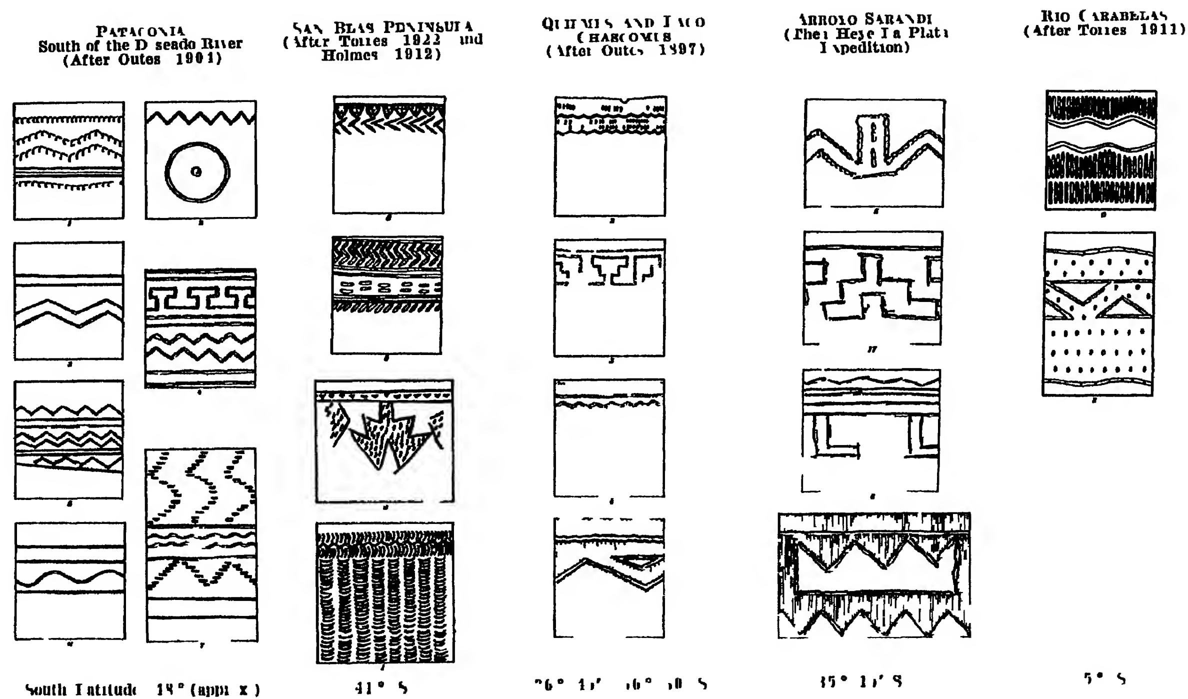
Incised sherds. Arroyo Sarandí Height of *a*, 3¼ in (14/7120)



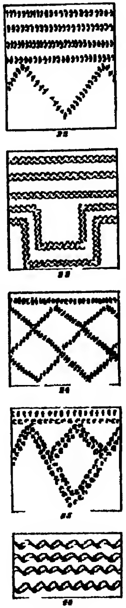
Incised sherds. Arroyo Sarandí. Height of *a*, 1¾ in. (14/7120)



Bone and antler implements. Arroyo Sarandí. Lengths, *e*, 9½ in.; others, 2½ to 4¾ in. (*a–e*, 14/4749; *f*, 8408; *g*, 4748; *h*, *i*, 4751)

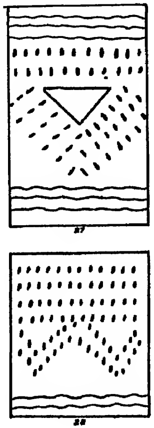

PATAGONIA
South of the Deseado River
(After Outes 1904)
SAN BLAS PENINSULA
(After Torres 1922 and
Holmes 1912)
QUILMES AND LACO
(CHASCOMUS)
(After Outes 1897)
ARROYO SARANDI
(Theo. Heye La Plata
Expedition)
RIO CARABELAS
(After Torres 1911)
South Latitude 48° (approx.)
41° S
36° 45′ 36° 30′ S
35° 15′ S
5° S

PARANÁ GUAZÚ EL CERRILLO
(Thea Heye-La Plata Expedition)



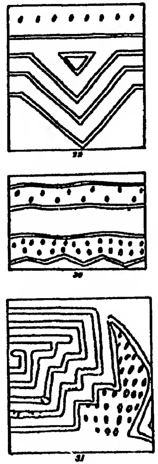
35° S

PARANÁ GUAZÚ NEAR THE BRAVO
(After Torres, 1911)



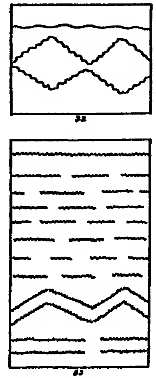
35° S.

PARANÁ GUAZÚ NEAR ISLA BOTIJA
(After Torres, 1911)



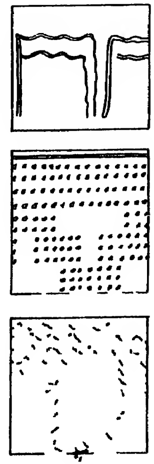
35° S.

BRAZO GUTIÉRREZ
(After Torres, 1911)

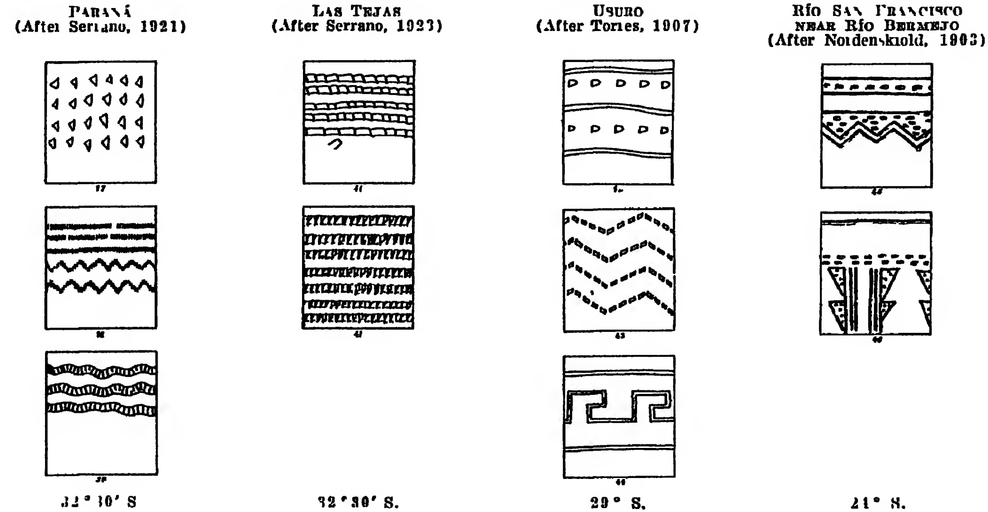


35° S

BRAZO LARGO NEAR THE PARANACITO
(After Torres, 1911)



34° 45′ S.


PARANÁ
(After Serrano, 1921)
LAS TEJAS
(After Serrano, 1923)
USURO
(After Torres, 1907)
RÍO SAN FRANCISCO
NEAR RÍO BERMEJO
(After Nordenskiold, 1903)
32° 10′ S
32° 30′ S.
29° S.
21° S.

[Annals N. Y. Acad. Sci., Vol. XXXIII, pp. 233-282, Feb. 1, 1932]

THE TETRAD-DIFFERENCE CRITERION AND THE MEASUREMENT OF MENTAL TRAITS*

By Henry E. Garrett and Anne Anastasi

CONTENTS

INTRODUCTION

In the physical sciences progress in precise measurement seems to consist largely in an increasing refinement both of the tools used and of the things measured. In physics, for example, with increasing precision in measurement, the molecule, the atom, and the electron have successively been regarded as ultimates—and the end is not yet. What is true of the physical sciences is becoming increasingly true of psychology, although progress here has not been so great, nor can steps in the refinement of measures be so clearly indicated. One of the reasons for this slackness has been the enormous popularity of the "general intelligence" tests. The really astonishing success of the Binet and the Army Alpha tests of general intelligence set many psychologists hard at work attempting to find measures of this broad hypothetical ability. Opinions as to what constitutes general intelligence have been many and varied—and often contradictory (*29*)†; but most psychologists have believed, or have seemed to believe, that a wide range of work-samples involving the knowledge and use of words and numbers would, when combined into a total score, give a valid index of general ability. There are today nearly a score of tests of general intelligence varying much *inter se* as to length and content. The positive correlation among these tests indicates clearly that they are measuring much in common; while their lack of perfect correlation shows even more clearly that they

* The publication of this paper has been made possible through a grant from the income of the Esther Herrman Fund.

† Throughout the present paper the numbers in italics enclosed by parentheses refer to works similarly designated in the Bibliography.

cannot all be measuring the same thing in the sense in which a centimeter and a foot rule both measure height.

One may admit that general intelligence tests are useful and at the same time feel that such inclusive batteries oftentimes obscure as much as they reveal. In recent years the increasing acceptance of this view is seen in the tendency among many psychologists to veer away from the measurement of general ability as a gross total, and to try to analyze, instead, the various aptitudes which seem to enter into a total score obtained from a general intelligence battery. If what we call general intelligence is really a composite of 5 or 20 or 100 disparate or even relatively disparate traits, then a composite "intelligence" score is almost as meaningless as a rating in "general health" arrived at by adding together one's systolic blood pressure, height, cephalic index, reaction time, and basal metabolic rate. Put differently, unless general intelligence can be made to refer to some unitary ability, the term can have little value as a scientific concept. At least one study of group differences in general ability has been repudiated by its author, because the total scores when analyzed were found to contain more than one independent ability (*3*). Doubtless many other studies of race and sex differences could be shown to be faulty because of this difficulty. It is perfectly fair to compare two groups in such clearly defined characteristics as height, or reaction time; but we have no right to speak of one group as being superior "generally" to another if the comparison has been made in terms of a group test composed of sub-tests which contain little in common. Let us suppose, to make this point clearer, that we have two groups, one of which is known to be superior in trait *A* and the other known to be superior in trait *B*. *A* and *B* are assumed to be fundamentally unrelated. Under these conditions, a group test which contains a large amount of factor *A* and a small amount of factor *B* will yield a composite score which is fair to neither group; the superiority of the first group in *A* will be lessened, and the superiority of the second in *B* entirely obscured. What is urgently needed in such cases is a method whereby independent mental functions may be located (if such exist) and measured. Such measures should consist preferably of an estimate of the function itself in individual scores; or if this is not possible, of its importance to the group—that is, of its role in the total ability measured.

In the study of mental organization, the most important techniques and methods used by psychologists have been contributed by C. Spearman and his school. During the last twenty-five years, this group has published many researches designed to locate and measure those general

and specific factors or ability-variables which appear in mental activity, as well as certain sub-general or "group" factors, *i. e.*, functions common to a limited number of abilities, but not to all. Much of Spearman's work has been concerned with establishing the existence of a general common factor (called g) throughout all cognitive (roughly intellectual) abilities. Spearman's Two-Factor Theory is too well-known to require presentation here (*25*, Chapter IV). Moreover, the present writers are not especially interested in Spearman's theory nor in his interpretation of g, but rather in the general method whereby a factor or ability common to a group of variables may be detected and measured. It is sufficient, therefore, to point out that since 1924 Spearman has employed the method of tetrad–differences instead of the older intercolumnar correlation as his final criterion of the presence of a general, group, and specific factors. Apart from its place in Spearman's system, the tetrad method is a valuable and ingenious analytic device. Nevertheless it has seemed to the writers that this method is subject to restrictions which have not always been recognized, and that in several studies in which it has been used proper precautions against these limitations have not been taken. This paper, therefore, is an attempt at evaluation of the tetrad–difference method in the study of mental traits. In Part I we propose to investigate several conditions, largely statistical, which one must recognize in applying the method of correlational or tetrad analysis; and in Part II certain studies of traits are considered which we believe to be faulty, either because of failure to realize certain limitations in method, or because of errors in interpretation. It will be necessary, first, to give a brief résumé of the tetrad method in order to furnish the proper setting for subsequent discussion.

Given any four tests, designated 1, 2, 3, 4, it is possible to compute six intercorrelations r_{12}, r_{13}, r_{14}, r_{23}, r_{24}, r_{34}, the subscripts denoting the tests correlated. From these six r's we can construct six tetrad equations by taking the r's in groups of four, as follows:

$$
\begin{aligned}
t_{1234} &= r_{12}r_{34} - r_{13}r_{24} & \qquad t_{1324} &= r_{13}r_{24} - r_{12}r_{34} \\
t_{1343} &= r_{12}r_{34} - r_{14}r_{23} & \qquad t_{1423} &= r_{14}r_{23} - r_{12}r_{34} \\
t_{1342} &= r_{13}r_{24} - r_{14}r_{23} & \qquad t_{1432} &= r_{14}r_{23} - r_{13}r_{24}
\end{aligned}
$$

The four r's upon which a tetrad depends are exactly indicated by the order of the subscripts in the tetrad (*15*, p. 47). Only the first two tetrads are independent; the third is the difference between #2 and #1, while the last three are simply the first three with signs changed. According to the Two-Factor Theory, when four tests dealing with cognitive abilities yield tetrads which are equal to zero within their *PE*'s, the intercorrelations among the tests may be attributed to one

general factor[1] (called g by Spearman) running through all four tests, plus, in addition thereto, a varying number of factors specific to each test (called s by Spearman). That the tetrads will equal zero when each test-variable is composed of one general factor plus specifics may be readily shown (*15*, p. 48). The converse theorem, namely, that when the tetrads equal zero, the four abilities are divisible into a general and specific factors may also be demonstrated (*25*, Appendix III).

If the tetrads do not equal zero within their *PE*'s, group factors common to two or three of the four tests are generally indicated; and in addition there may or may not be a general factor present. Group factors, according to Spearman, usually appear among tests too much alike in form or in content, and are due to the overlapping of specific abilities.

The value of a tetrad in indicating the presence or absence of a single general factor common to four tests depends directly upon the size of its probable error, *e. g.*, $PE_{t_{1234}}$. This follows from the fact that, owing to errors of sampling and measurement, tetrads rarely exactly equal zero, even when it is known that only a general factor and specific factors are present. Formulas for the *PE* of a tetrad have been derived by Spearman and Holzinger (*27*), by Moul and Pearson (*20*), by Kelley[2] (*15*), and by Wishart (*33*). Spearman and Holzinger's formula is identical with that of Pearson and Kelley except that terms involving the squared tetrad as a factor are dropped out on the assumption that the "true" tetrad equals zero. The formula of Moul and Pearson and of Kelley is the more general and gives values slightly lower than those obtained by Spearman and Holzinger. Wishart's formula gives results somewhat higher than those found by the other two formulas; but the differences in *PE* got from all three are negligible, being of the order of .001.

The accuracy of a given tetrad depends upon the errors in its component r's. The selfsame factors which make for unreliability in correlation coefficients will also make for unreliability in tetrad analysis. Accordingly, in examining the adequacy of the tetrad equation for trait analysis we shall of necessity be concerned with the factors upon which the significance of an r depends. Topics to be considered in Part I have been divided under four heads: I. Sampling, II. Heterogeneity,

$$PE_{t_{1234}} = \frac{.6745}{\sqrt{N}} \Big[r_{12}^2 + r_{13}^2 + r_{24}^2 + r_{34}^2 + 2r_{12}\, r_{14}\, r_{23}\, r_{34} + 2r_{13}\, r_{14}\, r_{23}\, r_{24} - 2r_{12}\, r_{13}\, r_{23} - 2r_{12}\, r_{14}\, r_{24}$$

$$- 2r_{13}\, r_{14}\, r_{34} - 2r_{23}\, r_{24}\, r_{34} + t_{1234}^2 \left(r_{12}^2 + r_{13}^2 + r_{14}^2 + r_{23}^2 + r_{24}^2 + r_{34}^2 - 4 \right) \Big]^{\frac{1}{2}}$$

[1]The term general factor as used hereafter simply implies any factor common to a group of test abilities. There is no reference to Spearman's g, unless specifically stated.

[2]Kelley's formula is identical with that given by Moul and Pearson. It is as follows:

III. Chance Errors, IV. Some Limiting Conditions. These will be taken up in order.

PART I

I. Sampling

The amount of fluctuation in an r to be expected from sampling plus chance errors is given by the well-known formula, $PE_r = \frac{.6745(1-r^2)}{\sqrt{N}}$. This formula is based upon the assumption that the sample worked with is truly representative of its population. If the abilities to be correlated may be taken to be distributed normally in the population, probably the most practicable method of securing a good sample is to increase the size of the group obtained until the constants, means and SD's, show little fluctuation. In studying the effect of sampling we have tried out experimentally the effect upon the tetrad equation of increasing the size of the sample (1) when the "tests" contain one general factor plus specific factors; (2) when there are overlapping or group factors plus specifics, but no general factor; (3) when no common factors are present, all of the factors being strictly specific. The "tests" or variables employed in all of these set-ups have been arbitrarily arranged, scores being determined by dice throws.

Table I

Four tests, each of which contains a general factor (differently weighted), plus specific factors

Determiners	I	II	III	IV	V	VI	VII	VIII	IX
Test 1.......	5	1	1	....	....	....	....	....	....
Test 2.......	4	....	....	2	2	1	....	....	....
Test 3.......	3	....	....	....	....	....	4	....	....
Test 4.......	2	....	....	....	....	....	....	4	3

$$r_{12} = \frac{(5)\ (4)}{\sqrt{25+1+1}\ \sqrt{16+4+4+1}} = .77$$

$$r_{13} = \frac{(5)\ (3)}{\sqrt{25+1+1}\ \sqrt{9+16}} = .58$$

$$r_{14} = \frac{(5)\ (2)}{\sqrt{25+1+1}\ \sqrt{4+16+9}} = .36$$

$$r_{23} = \frac{(4)\ (3)}{\sqrt{16+4+4+1}\sqrt{9+16}} = .48$$

$$r_{24} = \frac{(4)\ (2)}{\sqrt{16+4+4+1}\sqrt{4+16+9}} = .30$$

$$r_{34} = \frac{(3)\ (2)}{\sqrt{9+16}\ \sqrt{4+16+9}} = .22$$

This technique, while artificial, eliminates chance errors (there is no attenuation effect) so that fluctuations in the values of the same r in successive samplings are dependent entirely upon sampling errors. The three experiments as outlined are described in order..

Experiment 1

The constitution of our four variables is shown in Table I. Each test has determiner I as a general factor and one, two, or three other determiners as specific factors. To make the situation more concrete, these variables might be thought of as four tests of memory. Each would then contain the same common memory factor, differently weighted, and at least one specific factor (these are also differently weighted) such as a distinctive characteristic of form or material. Thus, Test 1 consists almost entirely of the general factor, while Test 4 has a heavy dosage of specific elements. All determiner values are, of course, arbitrary and were selected so as to give a fairly wide range of r's among the variables. The theoretical "true" r's for these four tests are given in Table I. These values have been calculated by dividing the products of the common determiners (general factor) by the square root of the product of the sum of the squares of all the determiners in the first variable by the sum of the squares of all of the determiners in the second variable. This formula is readily derivable from the ordinary product-moment formula. It has been attributed by Hull to Poisson (*13*, p. 230).

It seems to the writers that the method used in making up our hypothetical tests is superior to that employed by Thomson (*4*, Chapter X). Thomson's factors—general, group, and specific—all had the same weight in the hypothetical abilities measured by his "tests"; their values varied only with the individual, *i.e.*, with the dice throws. Our factors, on the other hand, are weighted twice; once for the ability or aptitude and again for the individual. According to this scheme, a cancellation test, say, might be thought of as depending intrinsically upon such factors as good eyesight, quick movement, accurate coordination perhaps,—all differently weighted. In addition, these same factors would have another set of weights which depend upon the separate abilities of the individuals taking the test.

Since the determiner weights are constant for a given test, we may find the "scores" of any given number of subjects in the four tests by throwing 9 dice (the total number of determiners). The numbers upon the die faces opposite each determiner are taken to represent the degree to which each hypothetical subject possesses the determiner in

question; and each individual weight is multiplied by the test weight to give the "score". For example, if for Subject *A* our 9 dice fall 4, 6, 3, 2, 1, 3, 2, 5, 6, *A*'s score is $5 \times 4 + 1 \times 6 + 1 \times 3 = 29$ in Test I; $4 \times 4 + 2 \times 2 + 2 \times 1 + 1 \times 3 = 25$ in Test II; $3 \times 4 + 4 \times 2 = 20$ in Test III; $2 \times 4 + 4 \times 5 + 3 \times 6 = 46$ in Test IV. If a determiner does not appear in a test, its value for that test is, of course, zero.

In the manner described, 9 dice were thrown 200 times to give a sample representing 200 individuals or cases. Complete sets of intercorrelations were then calculated for the 8 successive sets of 25 cases;

TABLE II

Intercorrelations and tetrads of tests shown in TABLE I

	r_{12}	r_{13}	r_{14}	r_{23}	r_{24}	r_{34}	t_{1234}	t_{1243}	t_{1342}
"True" values	*.77*	*.58*	*.36*	*.48*	*.30*	*.22*	*.00*	*.00*	*.00*
$N = 25$									
1	.53	.53	.28	.47	−.02	.09	.06	.08	−.14
2	.77	.45	.45	.45	.41	.37	.10	.08	−.02
3	.72	.62	.36	.23	.13	.24	.09	.09	.00
4	.78	.72	.40	.65	.38	.24	−.09	−.07	.02
5	.75	.57	.53	.39	.42	.19	−.10	−.06	.04
6	.73	.61	.21	.61	.23	.40	.15	.16	.01 ± .08
7	.80	.67	.48	.58	.46	.18	−.16 ± .04	.13	.03
8	.81	.63	.41	.48	.45	.25	−.08	.01	.09
$N = 50$									
1	.63	.48	.38	.45	.18	.20	.04	−.05	−.09 ± .04
2	.78	.77	.38	.54	.28	.17	−.08	−.07	−.01 ± .05
3	.73	.53	.33	.48	.33	.29	.04	.05	.01
4	.81	.65	.43	.54	.43	.21	−.11	−.06	.05
$N = 100$									
1	.66	.60	.42	.48	.25	.19	−.02	−.08 ± .04	−.06
2	.77	.60	.38	.51	.39	.25	−.04	.00	.04 ± .02
$N = 200$	.74	.57	.37	.49	.30	.22	−.01 ± .03	−.02 ± .03	−.01 ± .02

for the 4 sets of 50 cases; for the 2 sets of 100 cases; and for the whole sample of 200 cases. Table II gives these intercorrelations, and the tetrads calculated from them for the different samplings. At least three facts stand out in the table: (1) that *r*'s computed from small samples may vary widely from their "true" values (*13*, p. 226); (2) that tetrads based upon such incorrect *r*'s may give a very false picture of the basic constitution of the variables concerned; and (3) that the larger the sample, the nearer do the calculated *r*'s and tetrads approach their true values. The *PE*'s of the tetrads based upon 25 cases are of the order .07. The *PE* of .01, which is the smallest *t* (except 0), is .08; that of .16, the largest, is .04. None of these tetrads, to be sure, is 5 times its *PE*, the standard set by Spearman as necessary to establish a significant deviation from zero. However, two of the 24 are 4 times their *PE*'s and 13 are somewhat larger, only 9 being less. This, plus the fact that

the absolute values of the tetrads are large and the samples small (*i. e.*, 25), makes any definite conclusion as to the constitution of our 4 tests unwarranted. There is little evidence of a general factor plus specifics; indeed, if anything, the evidence as it stands points toward overlapping group factors. We must regard any diagnosis as a guess, however, and one guess is as good as another.

When $N = 50$ and even 100 the tetrads are still too large to make possible a definite statement as to the factors operative in our 4 tests. Five of the 12 tetrads based upon 50 cases are larger than their *PE*'s (which are of the order .05) and only two are probably insignificant because of their size. The first sample of 100 cases yields tetrads which suggest, at least, small group factors; the second sample of 100 has no really significant tetrads, and a general factor plus specifics is probably a sufficient explanation of the intercorrelations. When $N = 200$ the three tetrads are clearly insignificant (the largest, $-.02$, has a *PE* of .03) and the conclusion that we have a single general factor plus specific factors seems entirely justified.

As we have said, Spearman set 5 times its *PE* as the value which a tetrad must reach before it can be accepted conclusively as representing a significant deviation from zero. Such a standard, unless considered in connection with all other available evidence, will surely stack the cards heavily in favor of the Two-Factor Theory. The size of the sample worked with (N in the *PE* formula) affects the PE_t to a far greater extent than the sizes of the intercorrelations. In order to be practically certain of finding a general factor, therefore, all one needs to do is to keep down the sample to 25 cases or less, as it is next to impossible for a tetrad to be significantly greater than its *PE* under such conditions. However, this is an extremely dubious test of the presence of a general factor, although Spearman does not seem to think so. Commenting upon some work on perseveration by Heymans and

TABLE III

Four tests containing overlapping group factors, specific factors, and no general factor

Determiners	I	II	III	IV	V	VI	VII	VIII	IX	X
Test 1........	3	2	..	..	1	..	1	..	..	..
Test 2........	..	5	4	..	..	8	..	1	..	..
Test 3........	7	..	2	6	..	..	..	..	1	..
Test 4........	..	..	..	3	5	2	..	..	..	1

$r_{12} = .25 \qquad r_{23} = .08$

$r_{13} = .57 \qquad r_{24} = .25$

$r_{14} = .21 \qquad r_{34} = .30$

$$t_{1234} = (.25)(.30) - (.57)(.25) = -.07$$
$$t_{1243} = (.25)(.30) - (.21)(.08) = +.06$$
$$t_{1342} = (.57)(.25) - (.21)(.08) = +.13$$

Brugmans (*25*, p. 295) in which a tetrad of .20 ± .13 was secured, Spearman writes: "the tetrad difference does indeed have the high-looking value of .20; but even this becomes insignificant on comparing it with its *PE* which is .13. The reason for the latter being so large, of course, is the very small number of subjects, 15 only." Spearman's last sentence is entirely correct; his first statement almost certainly wrong on two counts: (1) as it stands the chances are nearly 6:1 that the tetrad of .20 does represent a significant deviation from zero; (2) no definite conclusion can possibly be drawn regarding the significance of a tetrad which is based upon r's calculated from only 15 cases, especially when its absolute value is as large as .20.

It is encouraging to note that although as N increases both the tetrads and their PE_t's steadily decrease, the tetrads decrease faster than their PE_t's. The general result of this experiment should serve to make us extremely skeptical of tetrad analyses into a general factor and specific factors when small samples are employed.

Experiment 2

In our second experiment, four tests were made up so that each variable overlapped the other three, but no common factor ran through all four. One specific factor was assigned to each test, and the weights of common factors differ in size in order to make the set-up as general as possible. The constitutions of our four tests are shown in Table III, together with the true r's and tetrads calculated from these r's. All of

TABLE IV

Intercorrelations and tetrads of tests shown in TABLE III

	r_{12}	r_{13}	r_{14}	r_{23}	r_{24}	r_{34}	t_{1234}	t_{1243}	t_{1342}
"True" values	*.25*	*.57*	*.21*	*.08*	*.25*	*.30*	*−.07*	*.06*	*.13*
$N=25$									
1	.46	.58	.42	.23	.31	.39	.00	.08	.08
2	.08	.53	−.16	−.16	.55	.00	−.29±.08	−.03	.26
3	.37	.44	.18	.31	.33	.33	− 02±.08	.07	.09
4	.28	.44	.05	−.17	.22	.15	−.05	.00	.05
5	.35	.57	.34	.12	.35	.24	−.12	.04	.16
6	.28	.66	.02	.24	.04	.40	.09	.11	.02
7	.39	.80	.54	.05	.16	.60	.11	.21	.10
8	.33	.49	.11	.21	.31	.24	−.07	.07	.14
$N=50$									
1	.21	.55	.09	.03	.43	.21	−.20	.04	−.24±.05
2	.27	.45	.11	−.01	.30	.21	−.18	.06	−.14
3	.34	.61	.10	.19	.09	.29	.05	.08	.03±.05
4	.35	.58	.28	.10	.22	.45	.03	.13	.10
$N=100$	.25	.52	.12	.01	.35	.22	−.13±.04	.05±.02	.18±.03
$N=200$	.27	.56	.16	.08	.26	.30	−.06±.03	.07±.01	.13±.02

the tetrads are greater than zero as they must be when group factors are present. As in the first experiment, dice (10 in all) were thrown to give a sample of 200 cases. Table IV gives the intercorrelations

calculated from 8 sets of 25 cases; 4 sets of 50 cases; one set of 100 cases, and from the total 200. The tetrads calculated from each set of 6 intercorrelations are also given along with the *PE*'s of the largest and the smallest tetrads for each sampling (zeros omitted). As found in Experiment 1, both the *r*'s and their tetrads vary widely from their true values when the samples are small. Since the *PE* of any tetrad based upon 25 cases is not far from .08, none of the tetrads based on these samplings is significant, in terms of its *PE*. As they stand, it seems probable that Spearman would claim them as giving evidence of his *g* and *s*. But in view of all of the data—the small samples, large *PE*'s, and large tetrads—we feel sure that no positive judgment is justified.

In the first experiment we noted that as the size of the sample increased, both the tetrads and their *PE*'s became smaller. But the decrease in the tetrads was so much more rapid than the decrease in their *PE*'s, that when $N = 100$ the probabilities were high that all of the tetrads were insignificant deviations from zero; and when $N = 200$, probability became practical certainty. In the present experiment, as the size of the samples increases, the PE_t's steadily become smaller. However, as the tetrads show no regular decrease, the probability that they represent significant deviations from 0 becomes

TABLE V

Showing the PE_t's for samples of different sizes, based upon the "true" tetrads of TABLE III

	$t_{1234} = -.07$	$t_{1243} = .06$	$t_{1342} = .13$
$N = 25$			
PE_t	.09	.04	.06
Significance Ratio	.77	1.50	2.16
$N = 50$			
PE_t	.06	.03	.04
Significance Ratio	1.16	2.00	3.25
$N = 100$			
PE_t	.04	.02	.03
Significance Ratio	1.75	3.00	4.33

increasingly greater. At $N = 100$, the chances are, respectively, 98 in 100, 95 in 100, and 100 in 100, that the three tetrads are significantly greater than 0; at $N = 200$, the chances are 91 in 100, 100 in 100, and 100 in 100, that the tetrads are significant, while the absolute values of the tetrads are almost identical with their true values. These results on the whole, are distinctly favorable to the tetrad method, since they indicate that the presence or absence of a central factor may be almost certainly shown, provided we work with adequate samples. This statement is conditioned, of course, upon the tests being highly reliable;

for, as already mentioned, all of the "tests" in the present experiments have reliabilities of 1.00.

The insecurity contingent upon the use of small samples in factor analysis is still more clearly seen, perhaps, in Table V. Here the *PE*'s of the tetrads based upon the true *r*'s shown in Table III have been calculated for samples varying in size. The significance ratio for each sampling is shown. When $N = 25$, the PE_t's are .09, .04, and .06, respectively, the significance ratios t/PE_t being .77, 1.50, and 2.16. The chances (in 100) that these tetrads are significant are 70, 84, 93. When $N = 50$, one tetrad becomes practically significant (98 chances in 100); and at $N = 100$ the chances are 88, 98, and 100 in 100, respectively, that the tetrads are significant. In order to bring the significance ratio of the least reliable tetrad up to 4.00 (the conventional standard), we should need 600 cases; to reach Spearman's standard of 5.00, we should need 900 cases.

Experiment 3

In our third experiment, four tests were made up to contain only specific factors. As there were no general and no overlapping group factors, all of the true *r*'s were necessarily zero. The factor patterns are shown in Table VI. As before, 200 throws were made (of 8 dice) and the *r*'s computed for 8 sets of 25 cases; 4 sets of 50 cases; 2 sets of 100 cases, and for the whole sample of 200 cases. The *r*'s and the tetrads are shown in Table VII, together with the PE_t's for the largest and smallest tetrads occurring when $N = 25$ and 50. When $N = 100$ and 200, all of the PE_t's were calculated. These results appear to be somewhat anomalous. For the small samples, the tetrads, as they stand, seem to be non-significant deviations from 0, but their *PE*'s are too large to make possible a definite decision as to factor constitution. With the samples of 100 and 200, the difficulty in interpretation becomes marked. Here some of the tetrads are statistically significant, and some are not, and it would be impossible to determine the factor set-up from the correlations alone. Certain other criteria are of aid, however. The intercorrelations are all quite small (when $N = 200$, they average .09) and many are negative, thus indicating that a general factor, if present, can hardly be real in a mathematical sense (*21*). Moreover, the tetrads exhibit no consistent pattern as the sample increases. In an actual experiment, of course, a knowledge of the tests employed, *i. e.*, their reliability, length, details of construction, and so on, would furnish many additional clues. On the whole, it is probable that the careful investigator would discard these data as of little posi-

TABLE VI

Showing four tests, containing specific factors only

Determiners	I	II	III	IV	V	VI	VII	VIII
Test 1	3	2	..	..	..	..	..	..
Test 2	..	..	5	1	..	..	..	..
Test 3	.	..	..	..	6	4	..	..
Test 4	..	..	..	..	..	..	8	3

$r_{12} = 0$ $\qquad r_{23} = 0$

$r_{13} = 0$ $\qquad r_{24} = 0$

$r_{14} = 0$ $\qquad r_{34} = 0$

TABLE VII

Intercorrelations[3] and tetrads[3] of tests shown in TABLE VI

	r_{12}	r_{13}	r_{14}	r_{23}	r_{24}	r_{34}	t_{1234}	t_{1243}	t_{1342}
"True" Values	*.00*	*.00*	*.00*	*.00*	*.00*	*.00*	*.00*	*.00*	*.00*
N=25									
1	−.0260	−.0969	.0421	−.1685	−.2594	−.2079	−.0197	.0125	.0322
2	.0606	.0488	−.1351	−.1606	.1372	.0177	−.0056	−.0206	−.0150
3	−.2512	−.0680	.0275	.2197	−.0223	.0823	−.0209	−.0330	−.0058
4	.0386	−.1667	.0167	−.2023	−.1156	−.0915	−.0228	−.0001 (±.0307)	−.0159
5	−.0037	.1561	.1222	.3383	−.2047	−.2638	.0330	−.0403	−.0093
6	.0268	.2071	.2365	−.1298	.1007	−.0913	−.0233	.0283	.0516
7	.0081	−.0889	−.4821	−.3857	.1440	−.0765	.0007	−.1865	−.1872 (±.0926)
8	.3995	.4646	.5421	.3197	.3799	.2062	−.0941	−.0909	.0032
N=50									
1	.0174	−.0318	−.0452	−.1640	−.0755	−.1077	−.0043	−.0093	−.0030
2	−.1001	−.0760	.0390	−.0081	−.1103	−.0254	−.0059	.0028 (±.0105)	.0087
3	.1556	.1471	.1991	.0382	−.0784	−.1178	−.0068	−.0259	−.0191
4	.1904	.2019	.0823	−.0736	.2961	.1066	−.0395	.0264	.0659 (±.0356)
N=100									
1	−.0346	.1324	−.0038	.0837	−.0816	.1094	.0070 (±.0135)	−.0035 (±.0101)	−.0105 (±.0013)
2	.1584	.1702	.1315	−.0048	.1138	.0052	−.0186 (±.0179)	.0014 (±.0131)	.0200 (±.0016)
N=200	.0849	.2220	.0841	.0478	.0157	.0739	.0060 (±.0012)	.0023 (±.0069)	−.0037 (±.0012)

tive value. This experiment shows, however, how tetrad analysis may break down if applied strictly without regard to other than statistical evidence.

Before concluding this section, a limitation to the general use of the PE_r formula deserves consideration. As already mentioned (p. 239) the assumption is usually made that r's obtained from successive samples are normally distributed. R. A. Fisher (*11*, pp. 163–177) has shown, however, that this assumption, while fairly well justified when r is small and the samples are large, becomes increasingly doubtful as r grows larger in absolute value. For small samples, say 20, an $r = .90 \pm .03$ is almost certain to return a badly skewed distribution in successive samplings, as the upper limit ($\pm$ 4 PE) is greater than 1.00 and r's of .95 to .98 will occur much less frequently than r's of .80 to .85. According to Fisher even r's of .60 to .75 will give skewed distributions

[3] Since some of the values in this table are so low, all r's and t's are reported to four decimal places.

if N is small; for r does not vary on a linear scale, and hence there is a much greater probability of values below than above the observed coefficient. To obviate these limitations which are inherent in the correlation method, Fisher has proposed a procedure whereby obtained r's may be translated into values on a scale which does give a normal distribution of values in successive samples. This z–scale is related to r in the following way:

$$z = \tfrac{1}{2}\{\log_e (1 + r) - \log_e (1 - r)\}$$

The variable z will be normally distributed even when the r's are not, since, according to Fisher, "as r changes from 0 to 1.00, z will pass from 0 to ∞. For small values of r, z is nearly equal to r, but as r approaches unity, z increases without limit".

This inadequacy of the ordinary PE_r formula, when the r's are large and the sample small, has a definite bearing upon tetrad analysis. Tetrads, of course, (as well as their PE's) depend directly upon the intercorrelations of tests and their PE_r's. It would seem much more probable that an $r = .80 \pm .02$ ($N = 200$) would return a normal distribution in successive samples than that an $r = .80 \pm .05$ ($N = 20$) would do so. The only practical remedy, apparently, is to work with large samples; and especially should the samples be large when the r's are large. The implication of the form of distribution of tetrads upon the PE_t's will be discussed later (p. 256).

We may summarize the findings of the present section on Sampling as follows:

1. When the PE's of the tetrads are high, no positive conclusion as to factor constitution is admissible, even if the tetrads are numerically small.

2. When the sampling is adequate and the reliabilities of the tests employed are high, the tetrad criterion appears to differentiate accurately between a factor constitution involving only a general factor and specific factors and one involving overlapping group factors with no central factor.

3. If there are no overlapping factors and the true correlations are zero, tetrad analysis from observed r's breaks down and must be supplemented by additional information, such as the signs of the r's, characteristics of the tests, absolute values of the tetrads, *etc.*

4. When the correlations are high and the samples small, application of the PE_r formula becomes precarious. As a consequence, values of t and PE_t are also doubtful. More adequate samples is the only practical remedy suggested.

II. Heterogeneity[4]

The problem of heterogeneity as usually understood[5] may be summarized briefly, as follows: If a sample is heterogeneous with respect to some variable, *V*, such as maturity, sex, age, race, social or educational background, then the correlation between any two variables *A* and *B* computed from this sampling will be higher than the "true" value if both *A* and *B* are correlated with *V* in the same direction (*i. e.*, both positively or negatively), and lower than the true value if *A* and *B* are correlated in opposite directions with *V*. Heterogeneity with respect to maturity is perhaps the best illustration of a case in which the correlation is raised; sex and race heterogeneity will lower a correlation if one of the groups combined is markedly superior to the other in ability *A* and markedly inferior in ability *B*.

Because of the disturbing effects of heterogeneity, the assumption is often made implicitly, and even sometimes explicitly, that a high degree of homogeneity is always desirable in a correlational study. This assumption deserves further analysis. Granted that heterogeneity does affect correlation, the first question is, should these effects be eliminated, and if so how far. What is meant by the "true" correlation, the size of which is affected by the use of a heterogeneous sample? As the writers see it, the question is not one of homogeneity versus heterogeneity, but rather one of the degree of heterogeneity required in a sampling. The failure to realize this distinction has caused some confusion and much justifiable criticism of the striving for homogeneity.

Before considering the various ways in which heterogeneity may alter the value of an *r*, let us define more exactly what is meant by the "true" value of an *r*. A true *r* is simply that *r* which would be obtained from the entire population from which our sample has been drawn. The first step, then, in any correlation study, is to define the population with which one intends to work. In many studies this is not done, and the tacit assumption seems to be that the investigator is dealing with the entire human race. It is impossible, however, adequately to sample the human race; and even if we could, the *r*'s computed from such a sample would have little meaning or value. The multiplicity of factors determining the size of an *r* obtained from such a varied population is too great to allow for any intelligent interpretation of the relationship found. Suppose, for example, that we should find an *r* of .90 between height and weight for the human race. Of what value is such an *r*? If we restrict our population to adults over twenty-one, the *r* may drop

[4] Errors of measurement, which constitute a prolific source of heterogeneity, are discussed separately in Section III.

[5] The reader is especially referred to recent discussions by T. L. Kelley (*15*) and Mark May (*17*).

to .40. In twelve-year-olds it may be .75,—and different for boys and girls. Or correlation of weight with age might be positive up to a certain age, and then negative. All of these specific results are more significant than a blanket statement of the relationships found in a broadly defined group affected by numerous quasi-unknown and wholly undetermined factors. Let us suppose again that the scores on an "intelligence test" are found to be correlated .85 with scholastic success, in a population ranging from the kindergarten to graduate students. Such an *r* is of no value in predicting the chances of success of a high school student whose score on the test is known. Within the high school group, or population, the *r* between scores on this particular test and school success may be .40 or .50, and this *r* gives us a much more adequate picture of the situation which we wish to describe. The upshot of this discussion is that for the sake of practical utility as well as of greater clarity of theoretical analysis and interpretation, *r*'s should be computed separately for different populations, and each population should be restricted to a greater or lesser degree (depending upon the purpose of the study) and rigorously defined. In many correlation studies the population is not restricted—at least, not purposely—and is not clearly defined.

When the population which we wish to represent has been clearly defined, the next step is to select a random sample from this population with which to work. Here the problem of heterogeneity enters. Heterogeneity of sampling may operate in three ways in disturbing the true relationship between two variables. In many, if not most, cases, heterogeneity affects the results in all three ways at once; but as it is possible for one effect to be operative in the absence of the others, each will be considered separately.

1. The effect of heterogeneity on the representative character of the sample

The most direct evidence of heterogeneity in a sample is shown in the variability of the traits measured. The more heterogeneous the sampling with respect to such factors as maturity, sex, race, *etc.*, the greater will be its variability whether we are measuring memory, height, speed of tapping, or intelligence. In a distribution which is a truly random sample of its population, *i. e.*, is truly representative, the variability will be less than that in the population, and the greater the reduction in N the greater the reduction in variability. T. L. Kelley (*14*, p. 104) has given the following table which shows the range covered (approximately) in different populations when the measures are distributed in accordance with the normal probability curve:

In case the total population is 10 range = 4 SD
In case the total population is 50 range = 5 SD
In case the total population is 200 range = 6 SD
In case the total population is 1000 range = 7 SD

It may be objected that since we do not know the variability in our population, we cannot know what variability to expect in a representative sample. This is only partly true; if we can assume normality in our population (and we usually can when dealing with mental tests) we may estimate from Kelley's table about what our range should be. When working with small samples, deviations far removed from the mean will then be discarded as atypical, much as the laboratory worker discards reaction times which are premature or delayed. A range of $\pm 3.5SD$ from the mean includes 9,995 cases in 10,000, and the same range includes 99.95% of the cases in 100, which may, in practice, be taken as 100%. In the larger sample, 5 cases fall completely outside the range indicated; in the smaller sample, all of the cases are within that range. The more extreme the deviation, the less the probability of its occurrence; hence, in small samples wide deviations cannot appear if these samples are truly representative of their populations. The effect of extreme deviations upon r is also greater when N is small. Just as one case affects the mean 10 times as much when there are 10 cases as when there are 100, so large deviations affect both the Σxy's and the SD's, the effect being greater the smaller the sample.

2. The effect of heterogeneity on the form of the distribution

Let us suppose that our population consists of twelve-year-old children and includes both boys and girls. If the girls are significantly superior or inferior to the boys in the ability measured, the distribution of scores will be bi-modal in the combined group, even though it is normal for either group taken separately. This condition may be present even when the sample is representative of its population. Whenever we lump together groups in which the central tendencies are significantly different, the resulting distribution will not be normal. The Pearson r does not assume a normal distribution; but, unless our distribution conforms to the normal type it is difficult to interpret our correlation coefficients. Simpson's study (*23*), in which the scores made by a group of hobos and a group of college students and professors were thrown into a single distribution, and correlations computed therefrom, is a flagrant illustration of heterogeneity resulting from the combination of dissimilar groups. It might be added that in Simpson's study the fact that his combined group did not represent a sample of any conceivable population is a further source of error.

3. *The effect of heterogeneity through correlation with a third variable or variables*

This is the most obvious effect of heterogeneity and is the one most generally treated. If the sample is heterogeneous with respect to age, and both variables are correlated positively with age, correlation may appear in the absence of any real relationship. This situation may exist when the sample is adequate with regard to the two conditions outlined above, provided the third or extraneous variable is continuous. If we include in our sample children ranging in age from 6–0 to 12–11, the distribution will be normal, at least for most measured abilities. On the other hand, if we lump into one sample only 12 year olds and 6 year olds, the resulting distribution will be bi-modal. If our third variable (or variables) is discrete (sex or race are examples) and is correlated in the same direction with the abilities to be related, our sample will not be normal, although it may be representative of its population.

The term spurious correlation was first applied to the correlation calculated between indices (*19*) but the term might apply equally well to those cases wherein the correlation between two tests is influenced by a third variable or variables. Apparently the best way of determining whether the correlation between two test-variables is intrinsic, *i. e.*, due to a common factor or factors, or is spurious, is to hold constant through partial correlation, or selection, or both, such obvious factors as age, sex, race, nurture. If the correlation between our variables persists under these conditions, the probability of common elements in the correlated variables seems good.

It is not always necessary, of course, rigorously to eliminate heterogeneity with respect to age, race, and other factors. If one is studying mental organization, relationships which arise from a community of function and not from extraneous influences are, of course, desired. But it must be remembered that homogeneity is not in itself sacred, and that spurious correlation is a relative affair. There is no reason why one should not work with a sample, heterogeneous as to sex or age or nurture, provided correlations dependent upon these influences are wanted, and the heterogeneity is fully recognized.

It may be well to illustrate how the correlation with a third and extraneous variable may give the impression of a common factor, and even satisfy the tetrad equation, when no general factor is actually present. Given four variables constituted as shown in the following table:

DETERMINERS

	I	II	III	IV	V	VI	VII	VIII
Test 1	3	2	..	..	..	..	..	..
Test 2	..	..	5	1	..	..	..	..
Test 3	..	..	..	..	6	4	..	..
Test 4	..	..	..	..	..	..	8	3

The true intercorrelation of these variables is zero in each case. Let us now assume that the four variables are all correlated positively with some other variable 5, such as age, as follows:

$r_{15} = .30 \qquad r_{25} = .50 \qquad r_{35} = .40 \qquad r_{45} = .20$

All of the intercorrelations with age partialled out will be zero. If variable 5 is not rendered constant, however, the intercorrelations of our four tests will be as follows:

$$r_{12} = .15 \qquad r_{23} = .20$$
$$r_{13} = .12 \qquad r_{24} = .10$$
$$r_{14} = .06 \qquad r_{34} = .08$$

The first three tetrads will be,

$$t_{1234} = .15 \times .08 - .12 \times .10 = 0$$
$$t_{1243} = .15 \times .08 - .06 \times .20 = 0$$
$$t_{1342} = .12 \times .10 - .06 \times .20 = 0$$

The tetrad equations are satisfied, but there is no general common factor present in the four tests, except age.

Heterogeneity with respect to a third variable can also give the impression of systematic group factors being present when the true constitution of four tests is a general factor plus specifics. The following example will illustrate this effect:

	I	II	III	IV	V	VI	VII	VIII	IX
Test 1	3	2	3	..	..	..	..	..	..
Test 2	5	..	..	3	2	..	..	..	..
Test 3	4	..	..	..	..	3	1	..	..
Test 4	6	..	..	..	..	..	..	4	2

In the table, one general factor runs through all four tests, and there are in addition two specifics to each test. The true r's are:

$$r_{12} = .5189 \qquad r_{23} = .6363$$
$$r_{13} = .5017 \qquad r_{24} = .6503$$
$$r_{14} = .5128 \qquad r_{34} = .6289$$

and $t_{1234} = t_{1243} = t_{1342} = .00$.

Now let the sample be heterogeneous with respect to another variable 5 which is correlated with the four tests as follows:

$$r_{15} = .6000 \qquad r_{35} = -.5000$$
$$r_{25} = .7000 \qquad r_{45} = -.8000$$

Variable 5 may be thought of as race or sex; tests 1 and 2 as traits in which the one group excels, tests 3 and 4 traits in which the other group excels.

With the introduction of variable 5 the intercorrelations of our four tests become:

$$r_{12} = .7147 \qquad r_{23} = .0430$$
$$r_{13} = .0492 \qquad r_{24} = -.2830$$
$$r_{14} = -.2339 \qquad r_{34} = .7283$$

and the tetrads are

$$t_{1234} = .5344$$
$$t_{1243} = .5306$$
$$t_{1342} = .0038$$

There is fairly good evidence from these tetrads of a group factor, through variables 1 and 2, or 3 and 4, or in both sets. (*15*, p. 69).

The rather obvious conclusion to be reached from the discussions of this section seems to be that, in studies of independent mental abilities or factors, influences making for heterogeneity must be controlled if we would begin with the fundamental or intrinsic relationships among our test-abilities. Kelley (*15*, pp. 24–33) has suggested that in such studies age, sex, race, and nurture (social and educational background), at least, should be ruled out. Language disabilities, physical handicaps, marked differences in motivation, are other obvious extraneous factors which should also be controlled.

Before leaving the topic of heterogeneity, two studies may be mentioned briefly, in which the effect of heterogeneity upon the tetrad criterion was examined by comparing the results obtained from a small homogeneous group with those secured from a larger heterogeneous group from which the smaller had been selected. In the first of these studies, Cureton and Dunlap (*9*) selected 87 boys of pure Japanese ancestry from a larger group of 396 high school seniors, exceedingly heterogeneous as to race. Correlations and tetrads for five mental tests were calculated for both groups. Largely as a result of the tetrad analysis, Cureton and Dunlap conclude that racial heterogeneity increases the relative importance of group factors and decreases the relative importance of "special" factors. In the second study, Holzinger (*12*, pp. 28–31) selected one group of 83 boys, all 15 years old, and another group of 63 boys, all 14 years old, from a larger group of 458 boys in which age ranged from 8 to 17 years. Correlations and tetrads for four physical measurements were calculated for the main group and for the sub-groups. Holzinger concludes from his tetrad analysis that heterogeneity with respect to age has no very appreciable effect upon the tetrad equations.

It seems to the writers that the conclusion of Cureton and Dunlap, as well as that of Holzinger, is open to considerable doubt. The reduction in the size of the sample in the homogeneous groups, with consequent increase in PE_t, would almost certainly produce a result sufficiently drastic to overshadow any effects which the correction for heterogeneity might have, even if we grant that the latter influence alone would have somewhat affected results. It should be added, also, that in Holzinger's data, the elimination of age variability reduced the correlations among his four physical measures by as much as .20 to .30; in one case the reduction was nearly .50. Even if the tetrads had been entirely unaffected by eliminating age (and they certainly were not) this loss in correlation with increasing homogeneity can hardly be passed over as of little importance.

III. Chance Errors

We may define chance errors briefly as those small, adventitious, plus and minus influences which operate to raise or reduce scores, the probability of an increase being as great as that of a decrease. In the present paper we are interested particularly in the effect of chance errors upon correlation coefficients and tetrads. The correction of an obtained r for chance errors is usually made by means of formulas for the correction of attenuation devised by Spearman (*24*). Spearman's full formula is

$$r_{xy} = \frac{\sqrt[4]{r_{x_1y_1} r_{x_2y_2} r_{x_1y_2} r_{x_2y_1}}}{\sqrt{r_{x_1x_2} r_{y_1y_2}}}$$

in which the r's in the numerator denote the correlation between alternate forms of tests X and Y (the subscripts designate the forms), and the denominator is the geometric mean of the two reliability coefficients. This formula assumes that the errors in the tests are neither correlated with each other nor with the true abilities measured by X and Y. Spearman's full formula is usually reduced to a much shorter form

in which the further assumption is made that the r's between different test forms of X and Y are all equal. Cureton and Dunlap (*8*), in a recent critical study of Spearman's formulas, have shown that the best estimate of a true or corrected r involves the SD's of the tests used; and that all correction formulas which make use of r's only, tend to underestimate the true value of r.

This underestimation of the true correlation is probably of slight significance, however, as in any case, except theoretically, the correction for attenuation procedure is not of much value. If the variables correlated have high reliability coefficients the correction is necessarily slight; on the other hand, if the reliabilities are low, the corrected r's cannot be considered to have very great validity. In the latter case, the corrected r's may be thought of as "theoretical maximum r's" which might have been expected if conditions had been more nearly ideal. In other words, they do not represent the experimental situation which actually existed.

Through preliminary testing and tryouts an investigator should be enabled to make his tests reasonably reliable; for if the tests used are unreliable to begin with, it would be better to discard the data entirely rather than to make use of elaborate statistical corrections. It would seem to be a dangerous principle to allow a mathematical calculation to take the place of a careful control of experimental conditions in the first place. When one is forced to work with test results already secured, or if a result under theoretically ideal conditions is desired, corrections for attenuation may, and probably should, be made. But such results must be considered to be theoretical and tentative rather than actual and certain.

Our present interest lies in the effect of correction for attenuation upon the tetrad criterion. Spearman has contended (*25*, Appendix VI)—and his contention has been echoed by Holzinger (*12*, p. 28)—that it is unnecessary to correct the r's for attenuation in a tetrad equation. This is, of course, true when the tetrad equation, *e. g.*, $t_{1234} = r_{12}r_{34} - r_{13}r_{24}$ is exactly zero. But if, as usually happens, the tetrad is numerically greater than zero, the unreliability of its component tests must inevitably affect the criterion. Let us suppose, for example, that we have four tests, 1, 2, 3, 4, in which the intercorrelations are as follows:

$$r_{12} = .60 \qquad r_{23} = .20$$
$$r_{13} = .50 \qquad r_{24} = .30$$
$$r_{14} = .40 \qquad r_{34} = .40$$

Let the population be 144 and the self-correlations of the tests be $r_{1I} = .80$; $r_{2II} = .70$; $r_{3III} = .75$; $r_{4IV} = .85$, a situation probably more optimistic than otherwise. The first tetrad equation, $t_{1234} = r_{12}r_{34} - r_{13}r_{24}$, becomes $.60 \times .40 - .50 \times .30 = .09$, and the PE_t by Kelley's formula (*15*, p. 49) is .04 (to two decimals). If we correct our r's by dividing both sides of the tetrad equation by, $\sqrt{r_{1I}r_{2II}r_{3III}r_{4IV}}$ the tetrad difference becomes .15. The PE of this corrected tetrad is .05 (see Appendix I for formula). The uncorrected tetrad is barely

twice its *PE*, and is probably not statistically significant; but the corrected tetrad is three times its *PE* and hence almost certainly represents a real deviation from zero. The *PE* of a corrected tetrad does not increase in proportion to the increase in the corrected tetrad itself. It seems clear, therefore, that in general correcting for the unreliability of tests does have a decided effect upon the tetrad criterion, always tending (except when reliabilities are 1.00) to increase the tetrad difference. Such an increase, of course, without a corresponding increase in *PE*, militates against the resolution of test abilities into a single general factor plus specifics.

If the tetrad ratio, $tr_{1234} = \frac{r_{12}r_{34}}{r_{13}r_{24}}$, is used as a criterion of a general factor, instead of the tetrad difference

$$t_{1234} = r_{12}r_{34} - r_{13}r_{24},$$

no corrections for attenuation are necessary. This is because both numerator and denominator of the fraction are divided by

$$\sqrt{r_{1I}r_{2II}r_{3III}r_{4IV}}$$

and hence the fraction remains unchanged. Despite this advantage, however, there are several considerations which would seem to make the tetrad difference preferable to the tetrad ratio. When all of the r's are positive a tetrad (like an r) may vary between $+1$ and -1 as extremes,[6] equalling zero when the inter r's are explicable in terms of a general factor and specific factors. The form of the distribution of a given tetrad in successive samples is not definitely known (*20*), but it seems reasonable to posit a normal distribution in most cases. As already indicated (p. 239) the distribution of an r in successive samples is at least roughly normal, provided the r is not too close to the limits of its range, and provided the sample is large. Coefficients of correlation, as well as their errors, may be correlated *inter se*, and this will, of course, affect the normality of the tetrad distribution. However, if the tetrads are small in absolute size and the sample large, the assumption of normality of distribution is probably not far fetched. If the tetrad is large the same objection enters here against the use of the *PE* formula which we noted in the case of large r's, and the assumption of normality becomes doubtful.

The tetrad ratio may vary from $+\infty$ to $-\infty$, provided one, at least, of the intercorrelations is negative; and its value, furthermore,

[6] When the r's are either positive or negative a tetrad may vary from -2 to $+2$.

will be indeterminate when both numerator and denominator approach zero. It equals 1.00 exactly when the inter r's can be explained as arising from a general factor and specific factors. If the r's are all positive, as they must be if there is a mathematically real central factor present, the tetrad ratio varies from zero to ∞. Assuming the true constitution of a group of tests to be a general factor plus specifics, fluctuations in a tetrad ratio due to sampling could range from a $+1$ to 0 in one direction and from $+1$ to ∞ in the other. Under these conditions it is difficult to see how normality of distribution could possibly be assumed, though it might still obtain if the samples are large and the PE's small. A point in favor of the tetrad ratio is that its PE is affected by errors in the correlation coefficients only, while the PE of a tetrad corrected for attenuation is affected by these, plus the errors in their reliability coefficients as well. The fact that the tetrad difference has been widely used in investigations by Spearman and his group is a practical reason, perhaps, for preferring it to the tetrad ratio.

IV. Some Limiting Conditions

In this section we shall consider (*1*) certain limiting conditions under which the tetrad equation does not hold, or else must be interpreted with caution; as well as (*2*) other procedures often employed with r's and tetrads which seem at least precarious as general techniques.

1. The tetrad criterion may be satisfied[7] *in the absence of a central factor, if the correlation of at least one test with the other three is zero or very low.*

It may readily be shown (*15*, p. 47) that the tetrad criterion will be satisfied whenever the constitution of four variables can be analyzed into one central factor running through all of the variables, plus, in addition thereto, a varying number of factors specific to each variable. This is not the only type of trait constitution, however, in which the tetrad equations may equal zero. If we set up hypothetical factor patterns and compute therefrom intercorrelations and tetrads, the following additional situations are found in which the tetrad criterion is satisfied:

(1) No general factor, one group factor through three variables, and specifics.

(2) No general factor, two overlapping group factors through three variables, and specifics.

(3) No general factor, three overlapping group factors through three variables, and specifics.

[7] *i. e.*, $t_{1234} = t_{1243} = t_{1342} = 0$.

TABLE VIII

Four tests containing no general factor, one group factor through three, plus specific factors

Determiners	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Test 1	4	2	1	1	..	.	..	..	..	..	..	..	..
Test 2	5	..	..	..	1	3	2	.	..	.	..	..	..
Test 3	8	..	..	..	..	..	.	2	1	3	.	..	..
Test 4	..	..	..	..	..	..	..	..	..	..	3	1	4

Four tests containing no general factor, two overlapping group factors through three variables, plus specific factors

Determiners	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Test 1	..	..	3	2	1	..	..	..	..	..	..	..	..	..
Test 2	4	..	..	..	..	3	1	2	.	..	..	..	..	..
Test 3	3	4	..	..	..	..	..	.	1	1	3	..	..	..
Test 4	..	5	..	..	..	..	..	..	..	..	..	4	2	1

Four tests containing no general factor, three overlapping group factors through three variables, plus specific factors

Determiners	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Test 1	..	..	..	3	2	1	.	..	..	..	..	..	..	..	..
Test 2	4	..	3	..	..	..	3	1	2	..	..	.	..	..	..
Test 3	3	4	..	..	..	..	..	..	..	1	1	3	..	..	..
Test 4	..	5	2	..	..	..	..	..	..	..	..	..	4	2	1

In Table VIII are presented the trait organizations, and in Table IX the values of the correlation coefficients and tetrads for these set-ups. In all cases the tetrads are exactly zero.

Objection may be raised that (*1*) we are dealing here with artificial and improbable situations, since in each case all of the correlations of one of the four tests with the other three are zero; and that (*2*) perfect zero correlations are rare in practice, and if found would surely never be employed in tetrad analysis. The answer to this is that our examples, while admittedly extreme, have been so selected purposely, because they represent a limit toward which many actual test situations approximate. If the correlations obtained in actual testing are not zero, but are fairly low and within the limits of chance deviation from zero, the resulting tetrads for any of the factor constitutions described, although not equal to zero exactly, will be very low and almost certainly well within their *PE*'s. For this reason, if tetrads are computed from a set of correlations in which the *r*'s of one test with the other three are all low, the satisfaction of the tetrad criterion will *not* prove the divisibility into a central and specific factors. The mere inclusion in a set of variables of one variable, the correlations of which with the other three fall within chance deviations from zero, is an adequate condition for the satisfaction of the tetrad criterion, *regardless of the constitution of the other three variables.* It would be a rather easy matter, therefore,

TABLE IX

Intercorrelations and tetrads of the tests shown in Table VIII

Trait Constitution	r_{12}	r_{13}	r_{14}	r_{23}	r_{24}	r_{34}	t_{1234}	t_{1243}	t_{1312}
No general factor, one group factor through 123, plus specifics	.6828	.7725	.0000	.7252	.0000	.0000	.0000	.0000	.0000
No general factor, two overlapping group factors through 23 and 34, plus specifics	.0000	.0000	.0000	.3651	.0000	.4915	.0000	.0000	.0000
No general factor, three overlapping group factors through 23, 24, and 34, plus specifics	.0000	.0000	.0000	.3203	.1359	.4714	.0000	.0000	.0000

to prove the divisibility of 4 variables into a general factor and specific factors by including in the group of tests one variable which, through low reliability or other defects, yielded low correlations with the other tests. Hence the use of unreliable tests is one way of practically guaranteeing that the tetrads will be zero (within their *PE*'s). Many of the tetrad differences reported in the literature (see Part II) have been computed from correlations obtained with extremely unreliable tests. When the tetrad criterion is satisfied in such cases we cannot be sure that we have a general and specific factors, instead of one of the spurious situations above described.

2. The satisfaction of the tetrad criterion gives no hint of the size of the central factor present.

Even when one is certain that a central factor has been adequately demonstrated, neither the size of such a factor nor its reality (in a mathematical sense) can be directly inferred from the fact that the tetrad equations equal zero. In order to estimate the size of the central factor, the correlations of the tests with this factor, or an analysis of the variance of the tests themselves, is necessary. To illustrate, suppose we have given four tests, 1, 2, 3, 4, in which the intercorrelations and tetrad equations are as follows:

$$r_{12} = .60 \qquad r_{23} = .50$$
$$r_{13} = .75 \qquad r_{24} = .04$$
$$r_{14} = .06 \qquad r_{34} = .05$$

$$t_{1234} = .60 \times .05 - .75 \times .04 = 00$$
$$t_{1243} = .60 \times .05 - .50 \times .06 = 00$$
$$t_{1342} = .75 \times .04 - .50 \times .06 = 00$$

The tetrad equations are all exactly equal to zero; and with adequate sampling we could be assured of a central and specific factors. How important is this central factor in the tests concerned? Spearman has devised formulas for obtaining the correlation of tests which satisfy the tetrad criterion with their central factor. In any four tests, a, b, c, d, the correlation of any one, say a, with its general factor g is $r_{ag} = \sqrt{\frac{r_{ab} \times r_{ac}}{r_{bc}}}$ or $\sqrt{\frac{r_{ab} \times r_{ad}}{r_{bd}}}$ or $\sqrt{\frac{r_{ad} \times r_{ac}}{r_{cd}}}$. If the three values obtained are not equal, it is customary to take their average. In our example, the r's of our four tests with their central factor are as follows: $r_{1g} = .95$; $r_{2g} = .63$; $r_{3g} = .79$; $r_{4g} = .06$. The percentage of the variance of each test which is attributable to the central factor, and the percentages attributable to specific factors plus chance errors, are as follows:[8]

[8] Under the given, conditions, the percentage of the variance of a test attributable to the common central factor is r^2_{ag}.

	Central factor	*Specific factors plus chance errors*
Test 1	.90%	.10%
Test 2	.40	.60
Test 3	.62	.38
Test 4	.004	.996

It is clear from the correlations of these tests with their central factor and from the analysis of their variances that the central ability while large in 1 and 3 is negligible in 4, if present at all. The fact that the tests were all given in the same room, or that the subjects all used pencils, furnishes a sufficient common factor, perhaps, to explain the correlations of test 4 with the other three.

This situation is clearly a further elaboration of the cases already described under No. 1 in this section. The correlations of test 4 with the other tests might easily arise as chance deviations from zero, unless the sample is very large. The analysis of variance furnishes a check on the spurious satisfaction of the tetrad equation.

For the common factor to be real mathematically, all of the correlations in a four variable set-up must be positive. If one, two, or three intercorrelations are negative, one or more of the correlations of the four tests with their common central factor (assuming always that the tetrad criterion has been satisfied) will equal the square root of a minus quantity, and hence be imaginary.

3. The interpretation of a central factor, when the tetrad criterion has been satisfied, depends upon an analysis of the tests employed; it cannot be assumed forthwith to be Spearman's g.

This proposition can best be made clear, perhaps, by an illustration. In a recent study Holzinger (*12*) gives the following data taken from Kelley (*15*) as an illustration of Spearman's basic theorem. We may follow Holzinger's nomenclature as follows:

Let x_1 = a test of reading speed
x_2 = a test of arithmetic power
x_3 = a test of memory for words
x_4 = a test of memory for meaningless symbols
x_5 = a test of memory for meaningful symbols

The ten intercorrelations of these five tests based on 140 cases yield fifteen tetrads which, in general, seem to be chance deviations from zero, and hence indicative of a single general factor plus specifics. The correlations of the tests with this central factor are $r_{1c} = .280$; $r_{2c} = .275$; $r_{3c} = .641$; $r_{4c} = .762$; $r_{5c} = .973$. Is the factor common to this set of tests necessarily Spearman's g? Holzinger apparently thinks

that it is. He writes ". . . The so-called memory tests appear to be most highly saturated with g, but an examination of these tests shows that they are of the intelligence test variety, rather than pure measures of retentivity which has a low correlation with g."

This interpretation is almost certainly erroneous. The memory tests were designed specifically to measure retentivity; they have an average correlation of .61 *inter se* and an average intercorrelation of .23 with reading speed and arithmetic power. They appear upon examination to be as genuine tests of memory as the other two tests are measures of reading and arithmetic. If we compute the percentages of the variance of each test attributable to the general factor and to the specifics (plus chance errors) we get the following results:

	Per cent. of variance due to	
	The General Factor	*Specific Factors Plus Chance Errors*
Test 1	.08	.92
Test 2	.08	.92
Test 3	.41	.59
Test 4	.58	.42
Test 5	.95	.05

It seems evident that the ability central to these tests is a memory factor and not Spearman's g. Instead of the memory tests being highly saturated with g, therefore, it would be more accurate to say that the reading and arithmetic tests are slightly saturated with memory, 92% of their variance being due to specific elements. The tetrad equation is a purely mathematical device which enables us to locate a central factor. The interpretation of such a factor, however, is a matter of psychological and not statistical analysis.

4. The employment in tetrad analysis of the average of a set of r's *instead of the* r *from the entire sample is a dubious procedure, to be used with caution.*

This proposition follows from the fact that correlation coefficients do not vary on a linear scale, and that a unit does not mean the same thing at different points of the scale. The difference between an r of .20 and one of .30 is by no means so great as that between an r of .70 and one of .80. Measured on R. A. Fisher's z-scale (*11*, p. 177), in fact, a correlation of .99 differs from one of .95 by as much as a correlation of .71 differs from one of .01. To take another extreme case, the average of an r of + .60 and an r of − .60 is zero; thus two perfectly good coefficients combine to yield exactly no result. When several of the coefficients in a set of inter r's are negative, or when coefficients

vary widely in absolute value, averaging may give results which are clearly incorrect. This situation is illustrated in Table X.

TABLE X

To show the effect of averaging r's which differ widely in absolute value. N is taken as 50 in each sample.

	(1) r's between same tests in successive samples	(2) z-scale values	(3) r^2
	.20 ± .09	.20	.04
	.40 ± .08	.42	.16
	.60 ± .06	.69	.36
	.80 ± .03	1.10	.64
	.90 ± .02	1.47	.81
Sum	2.90	3.88	2.01
Aver.	.58 ± .03	.78	.40
r	.58	.65 ± .03	.63 ± .03

The average of the 5 r's in Table X is .58 ± .03, basing the *PE* on a sample of 250 cases. When these r's are transformed into z values and averaged, the r corresponding to the average z (.78) is .65. That this value is probably closer to the true value of r to be expected from the whole sample than is .58, is indicated by the check applied in column 3. It is well known that r^2 gives the percentage of the variance of one correlated variable which may be thought of as dependent upon variations in the other (*10*, p. 375). Each r, therefore, has been squared to give the effective value of each correlation coefficient; these results were then averaged and the square root of this average taken, giving .63 as the mean effective value of r. This figure is much closer to the r obtained from the z values than to that value obtained from the arithmetic mean of the observed r's. The *PE*'s of the average r's are based in each instance upon 250 cases. It might be objected that the *PE* of an r obtained by averaging the r's found in five samples of 50 each should not be based upon 250 cases. Justification, however, for this procedure (which is the common one) is found in the fact that the *PE* of the average r obtained from the *PE*'s of the component r's is practically identical with the *PE* obtained from the ordinary PE_r formula for $N = 250$ cases.[9] Moreover, if the *PE* of z (.78) is calculated (*11*, p. 164) and this value transformed into the r-scale, the *PE* of the r (.65) equivalent to a $z = .78$ is .03.

If the r's from successive samples fall within a fairly narrow range and at neither extreme of the scale, the arithmetic mean will give

[9] This is assuming that the r's in successive samplings are uncorrelated, as they would be if fluctuations were due to sampling only. (*5*, p. 48).

results which are quite accurate enough for most purposes. This is shown concretely in Table XI in which the r's vary from .20 to .60 in steps of .05, with one exception (there are two .60's).

TABLE XI

To show the effect of averaging r's which are fairly close together on the r–scale. $N = 50$ in each sample.

	(1) r's between same tests in successive samples	(2) z–scale values	(3) r^2
	.20 ± 09	.20	.0400
	.25 ± .09	.26	.0625
	.30 ± .09	.31	.0900
	.35 ± .08	.36	.1225
	.40 ± .08	.42	.1600
	.45 ± .08	.48	.2025
	.50 ± .07	.55	.2500
	.55 ± .07	.62	.3025
	.60 ± .06	.69	.3600
	.60 ± .06	69	.3600
Sum	4.20	4 58	1.9500
Aver.	.42	.46	.1950
r	.42 ± .04	.43	.44

The same procedures shown in Table X have been followed here. The arithmetic mean of the obtained r's is .42 ± .04; the r from the average z is .43; and the r from the r^2's is .44. This close correspondence results from the fact that over the middle of the scale r values are practically linear.

(5) *The practice of pooling tests in order to secure high correlations with estimates of traits or ratings may give a false notion (1) of the existence of a trait; or (2) of the importance of a trait when such is known to be present.*

The pooling of tests into a single measure is a favorite procedure of Spearman and his students. From the r's between such pools and estimates of ability, generalizations have often been made which, it seems to the writers, may easily be misleading. This is especially true if the tests have low intercorrelations and low reliabilities. The formula for the correlation of a single variable, or criterion, with a pool of equally weighted tests is:

$$r_{CP} \quad \frac{\sqrt{N} \quad \bar{r}_{CT}}{\sqrt{\quad I + (N - I)\ \bar{r}_{TT}}}$$

(see Kelley, *14*, p. 200, #151). In the formula r_{CP} is the correlation between the criterion and the pool of tests; N = the number of tests;

$\bar{r}_{CT}$ = the average of the correlations between the criterion and the separate tests; $\bar{r}_{TT}$ = the average intercorrelation of the tests.

Examination of this formula indicates that the coefficients which it gives will always be fairly high if the tests are numerous and their intercorrelations low. Thus, if the number of tests is 9, their average correlation with the criterion .40 and their average intercorrelation .30, the r between pool and criterion is .65; for the same situation, except that the average intercorrelation is .20, the r between the pool and the criterion equals .74. These relatively high r's do not mean necessarily that the tests and the criterion possess any substantial factor in common; on the contrary, they probably mean that the criterion is so exceedingly complex and contains so many diverse elements that a large group of tests (even though fundamentally unrelated) can each measure a different bit of it. It may well be, of course, that a large share of the apparent unrelatedness of such tests arises from attenuation effects; and this would be especially true if the tests were very short or were poorly constructed (see Part II, p. 271ff.).

(6) *The method whereby the presence of a general factor and specifics is established by comparing the distribution of all possible tetrads in a table of correlations with the distribution to be expected by chance is of doubtful validity.*

Instead of evaluating single tetrads in terms of their *PE*'s, Spearman has customarily used a much more summary method in which all of the tetrads in a table are employed at one time. The total number of possible tetrads in a correlation table may be found from the formula 3_nC_4, wherein n = the number of tests employed. These tetrads, when plotted, give a histogram which must necessarily be bi-laterally symmetrical about zero as a median point, since each plus tetrad is matched by a minus tetrad of the same numerical value. Spearman's plan is to superimpose upon such a distribution of observed tetrads a normal curve of the same area, which presumably gives the distribution of tetrads to be expected from sampling errors alone. The *PE* of this theoretical distribution is obtained from a formula, the proof of which has recently been published by Spearman and Holzinger (*28*). If the *PE* of this theoretical distribution is larger than the *Q* (*PE*) of the distribution of observed tetrads, all of the latter values are taken by Spearman to be chance deviations from zero. Under such conditions a general factor and specifics would be a sufficient explanation of the correlations found. An observed tetrad (according to Spearman) must be at least five times the theoretical *PE* before its significance as a true deviation from zero is definitely established.

Several criticisms may be made of this technique. In the first place, the distribution of observed tetrads, while necessarily symmetrical, is not necessarily normal, as Pearson and Moul (*20*, pp. 267f.) have shown, using data cited by Spearman. Second, Spearman's assumption that sampling errors alone will give a normal distribution of tetrads has not been verified. As Kelley (*15*, p. 13) has pointed out, the probability is that such a distribution of tetrads would be skewed rather than normal, as chance errors in the *r*'s upon which the tetrads are based are known to be correlated; and hence the chance errors in the tetrads are also very probably correlated. Third, Spearman's stipulation that a tetrad must be five times its *PE* before its significance as a deviation from zero is established, tips the scale too heavily in favor of the Two-Factor Theory. If the sample is large, significance ratios much smaller than 5 may represent reliable deviations from zero.

PART II

The experimental study of mental organization, although comparatively recent in psychology, has already shown signs of reaching that dangerous stage where statements are handed down from one writer to another without careful examination into their original sources. Textbook writers, expecially, in their efforts at simplification, exhibit this tendency, which is natural enough to be sure, but which may unfortunately lead to serious misconceptions when concerned with a problem still in the formative stages. In the course of successive quotings and paraphrasings by different writers a tentative conclusion is likely to emerge more and more clear-cut and general, with the necessary restrictions and limiting conditions smoothed away. Perhaps it is a salutary procedure, therefore, to go back occasionally and examine original data.

The present section will attempt to evaluate some of the experimental papers most frequently cited as evidence for the existence of various hypothetical traits, or factors, in mental life. Our purpose is not to make an exhaustive survey of the literature on mental organization, but rather to illustrate, among other things, those principles developed in Part I, by reference to selected published data. The studies selected for illustration were chosen (1) because they have often been quoted and (2) because conclusions of considerable theoretical significance have been drawn from them.

The writers have previously (p. 00) disclaimed any interest in Spearman's *g* factor, other than in the possibility of revealing its existence by means of the tetrad criterion. They are not concerned with the nature

of *g* nor in its identification by Spearman with mental energy, intelligence, or whatnot; however, they do consider Spearman's conclusions to be speculative and as tending to go beyond the experimental and statistical facts. There seem to be, in general, two ways of attacking the problem of the existence or non-existence of a general intellective factor common to mental activities—the second method being in a sense a corollary of the first. The first method is to secure reliable measures of a very large number of mental functions from a group truly representative of its population, and large enough to make the *PE*'s of the order of .01 or less. Thorndike (*30*) has suggested as a crucial test that 10,000 16 year olds be measured in (1) pitch discrimination, (2) digit span, (3) opposites, (4) sentence completion, (5) definitions, (6) number series completion, (7) arithmetic problems, and (8) picture completion, by tests with reliability coefficients of .95 or better, and that these data then be searched for a general factor. If a thorough tetrad analysis revealed the presence of a common factor in data of this sort, and if this factor appeared in other groups with much the same weight and saturation within the different tests, we might regard the existence of a common intellective factor as proven. A second plan might be to select several fairly small batteries made up of tests chosen so as to sample a variety of functions, to establish the presence of a general factor in each battery, and (when such factors are found) to see whether the intercorrelations of these experimentally determined "*g*'s" are as high as the reliabilities of the batteries will permit. This second method could be employed to supplement the first, and might meet the criticism that Spearman's *g* is relative to the particular test set-up (*32*).

The main drawback to the first plan, it seems to the writers, is that when a wide range of functions is tested, the great complexity of the data make statistical analysis wellnigh impossible. This is brought out clearly in the recent work of Kelley (*15*). Using tetrad analysis as a starting point, Kelley has sought to analyze out the different independent factors in a set of mental tests. His method, in brief, was to determine tentatively the *SD* values of the different factors in each test; and then to refine these values by successive approximations employing the method of least squares. The number of approximations necessary was often astonishingly large. For example, Kelley finds the final factor weights in 10 tests for a group of 60 children in Grade III, after 45 approximations. When one considers the small population, the PE_r's of the tests employed, and the amount of calculation and tabulation necessary to get these factor weights, it hardly seems that the data warranted such elaborate statistical manipulation.

Kelley's method appears to be chiefly valuable as a means of preliminary analysis. It is not of much value, except theoretically, to know that a test of "reading speed" given to a Grade III group contains maturity, verbal, number, and speed factors with weights of .373, .661, .133, and .443, respectively (*15*, Table 32, p. 140). But it *is* important to know which factor weighs heavily in a given test, since what one really wants eventually is a reliable measure of each one of these "traits" separately. If the relative saturation of a test with a given factor has been determined, and is high, we may proceed to the task of constructing tests to measure this factor. At present, unfortunately, even with the best testing instruments we can only hope to do this very approximately and imperfectly, so far as the factor weights in individual scores are concerned. But we may estimate quite accurately the factor weights in a given ability for the group.

Of the many studies which Spearman has cited as specific evidence for the existence of his g factor, space permits us to analyze only two—those of Simpson and of Bonser (*23* and *2*). The data of these investigators are evidently considered especially valuable by Spearman, since he discusses them at length in his chapter on the existence of g in *Abilities of Man*. In fact, he refers to Simpson's study as "the investigation which has been most prominent in the literature on the topic" (page 145). The subjects in this experiment consisted of 17 university professors and advanced students, and 20 unemployed men of the hobo type, picked up at Bowery missions in New York City, a total of 37 subjects in all. As far as factor analysis is concerned, this group, besides being woefully inadequate as to size, illustrates all of the errors of selection discussed in Part I. Heterogeneous to a marked degree, the distributions for most of the 14 tests administered by Simpson are bi-modal, making the application of the product-moment method quite doubtful. Hence, the correlations are probably spurious (p. 248ff.) being due in large part to the wide differences in education and native equipment among the subjects, rather than to intrinsic relations among the abilities ostensibly measured by the tests. Some of the inter r's are unbelievably high. For example, the r between Completing Words and Hard Opposites is .98; the "A" Cancellation test and Hard Opposites, .64; Memory for Words and Memory for Passages, .82. We may profitably compare these r's with the following obtained by Carothers (*7*, p. 58) on 100 women freshmen: Completion and Opposites, .34; Cancellation and Opposites, .12; memory for words and logical memory, recollection, .35.

Simpson reports reliability coefficients for each of his two groups

as well as for the total sample. These r's range from .40 to .97 for the whole group of 37; from $-.41$ to .96 for the Good group, *i. e.*, the academic group; and from $-.10$ to .93 for the Poor group. The marked gap between the two groups in test performance is shown clearly by the wide differences in the reliability coefficients secured from the same test for each group separately, and for the whole group. To illustrate, the reliabilities for the whole group, for the Good group, and for the Poor group on certain selected tests, were, respectively, as follows: Scroll Test, .76, $-.04$, .71; Completing Words, .92, .27, .89; Drawing Lengths, .72, .42, .95. The high reliabilities of the tests for the whole group are undoubtedly spurious (see p. 248ff.), owing to the marked heterogeneity of the group.

Such correlational data, invalidated by almost every possible error of sampling and measurement, Spearman not only hails as proving the existence of his g factor when the older intercolumnar criterion is used (*26*), but later proceeds to calculate 3003 tetrads from it! The distribution of these tetrads conforms closely to the probability distribution, as such a hodge-podge of chance material might well be expected to do; and the median tetrad difference (.062) was found to approximate closely to the theoretical *PE* of .061. Spearman (*25*, p. 146) concludes that the close correspondence of the two distributions, theoretical and observed, "display[s] . . . one of the most striking agreements between theory and observation ever recorded in psychology. Indeed, it would not easily be matched in any other science. The divisibility, then, is indicated more decisively than ever." Considering the patent inadequacies of the data, one must admit that this conclusion is rather sweeping.

Bonser's study (*2*) is described by Spearman as "yet another work of exceptional importance for our purposes. . ." (*25*, p. 147). To be sure, this study is somewhat better adapted to the purposes of factor analysis than is Simpson's, since Bonser at least employed a sampling of 757 subjects. These were school children of both sexes in Grades IV, V, and VI, ranging in age from 8 to 16. Tests were devised by Bonser to measure "the most fundamental four phases of reasoning activity." These tests were classified under the following heads: mathematical judgment; controlled association; literary interpretation; and selective judgment. In addition, a spelling test was given "as an incidental problem for correlation" (p. 8). The last three types of reasoning tests probably measured reading comprehension and verbal or linguistic abilities for the most part, while even the mathematical judgment test was largely verbal, as it involved the reading of fairly intricate arith-

metic problems which had to be understood before they could be solved.

Bonser computed correlations both for grade and age groups, but it is only with the latter r's that we are concerned since these are used by Spearman (*25*, p. 147) in analyzing out his g factor. Correlations between the tests of each type of reasoning ability were reported by Bonser for different age groups, boys and girls being kept separate. Each age group covered 6 months, with the exception of the last which ranged from 14–6 to 16 years, making 12 age groups in all. The number of children in these different age groups ranged from 6 to 63. To illustrate the procedure more concretely, correlations were computed by Bonser between the two combined tests of mathematical judgment, say, and the two tests of controlled association for each of the 12 age groups, boys and girls being kept separate. The r's for the boys between each type of test were then averaged and it is these averages, combined with the averages of the corresponding r's found from the 12 age groups for girls, which were used by Spearman. Each r in the table with which Spearman worked, therefore, was based upon the average of at least 24 r's (more often 48, since there were usually more than one test under each type of reasoning); and these individual r's, in turn, were based upon from 6 to 63 cases and range from $-.87$ to 1.00! Surely average r's based on such data are not representative of the true relationship, (see p. 262) and have practically no validity. Yet Spearman reports that since the median tetrad difference (there were only 15) obtained from these data is .013 and the theoretical PE .011, the agreement between theory and result is "excellent" (*25*, p. 148).

Perseveration is another general factor purposed by Spearman and his students, and identified by him with the general "law of inertia." We shall examine two studies concerned with this alleged ability, from which Spearman not only deduces the presence of a perseveration factor but describes many of its attributes. With the following words Spearman concludes his introduction to Lankes paper (*16*) on perseveration: "This, then, is the problem undertaken by Dr. Lankes, to ascertain whether Webb's phenomenon[10] is only a special instance of some law of persistency of impressions, in general, or whether it is a law peculiar to the operations of the will. He arrives at a definite solution in the paragraphs that follow." Let us look more closely at the data which enabled Lankes and Spearman to reach this "definite solution" of their problem.

In his main experiment Lankes worked with 47 subjects, students of a Teachers' Training School. Eight tests of perseverative tendencies

[10] This refers to Webb's character factor "w".

in different types of performance were given to these subjects, and the scores so obtained intercorrelated with each other and with two other measures obtained from ratings. The first of these rating devices was a perseveration questionnaire of 14 items to be answered by each subject on a 4-point scale, containing the designations "yes, no, very much, never." The other measure consisted of estimates of "persistence-qualities" of character, which had been obtained by Webb on the same subjects. These estimates were the combined ratings of two judges on each of 8 traits, a 7-point scale ranging from + 3 to − 3 being used. (All correlations were computed by Spearman's Footrule formula and translated over into product-moment r's.) No systematic report is given of reliability coefficients; however, several coefficients found from retests as well as correlations between the average of all of the tests on the first and second days are reported for some of the tests. These r's were computed on those of the 47 students who were present when the retests were given, and cover a wide range of values. No reliability coefficient is given for the questionnaire. The intercorrelations of the tests when the two sets of ratings are included range from .51 to −.37 with a large number of zero and negligible r's and several negative values. Omitting the r's with Webb's character estimates the range of intercorrelations is from − .05 to .51, *PE*'s (not stated) being of the order .08 and .09. With a sample of 47 cases an r should be at least .30 to .40 to be statistically significant. We have shown on page 246 that very high correlations may result from errors of sampling alone, even when the true r is zero; hence it is more than probable that many of Lankes' correlations are insignificant deviations from zero, and can not be taken to indicate the presence of a common factor. When the 8 tests were pooled a correlation of .41 was obtained with the perseveration questionnaire, and a correlation of −.26 with Webb's character ratings. From the first of these correlations Lankes concludes, and Spearman agrees, that the presence of a perseveration factor through his tests has been demonstrated. The negative correlation of −.26 with the character ratings was interpreted to mean that the trait of perseveration is independent of Webb's will factor, described as "the persistence tested by the estimate of qualities of character and behavior." Lankes' use of a pool of tests is open to the criticism of this procedure advanced on page 264, especially as his test intercorrelations are all extremely low, thus increasing the chances of a spuriously high correlation between the pool and the questionnaire. It is difficult to see how the correlation of −.26 between the pool of tests and Webb's character estimates means anything, since the *PE* of this r is .09.

We are forced to conclude that Lankes' data prove nothing conclusive with regard either to perseveration or character.

A more recent study of perseveration has been carried out by Bernstein (*1*), working in Spearman's laboratory. Bernstein gave 10 tests of short duration to two groups of school children numbering 70 and 60 respectively. The subjects were all boys, the average age being 11 years 9 months in group 1, and 13 years in group 2, the range of ages not being stated. The reliability coefficients of these tests, obtained from the correlation of halves, ranged from .36 to .93. All of these tests were designed to measure perseveration. As a criterion, Bernstein secured estimates of perseveration on each subject from 2 teachers. These estimates consisted of ratings on a 7 point scale from + 3 to − 3 and were intended to show the ease with which the children changed from one school task to another. The reliabilities of these ratings, as determined by correlating the estimates of the two teachers, were .48 for the group of 70 and .52 for the group of 60. Bernstein attributes this low consistency to the fact that many other factors besides perseveration entered into the ratings (*1*, p. 17). The intercorrelations of the 10 perseveration tests were quite low, the average being .11; while the average correlation of these tests with the estimates was .28. In the first group the intercorrelations of the tests and estimates ranged from .08 ± .08 to .44 ± .06; and in the other group from .11 ± .09 to .46 ± .07.

Bernstein now pooled the 6 best tests for the first group and secured a correlation between this battery and the estimates of .48. The correlation between a pool of the 8 best tests in the second group and the estimates was .54. Although Bernstein keeps the results of his two groups separate, Spearman (*25*, p. 304), in quoting Bernstein's work, averages the *r*'s from the two groups and reports the correlation between estimates and the pool to be .51 for 130 subjects. Despite the extremely low intercorrelations of the perseveration tests, Spearman apparently thinks that the correlation of .51 between pool and estimates demonstrates the presence of a perseveration factor. He writes (*25*, p. 304): "All sorts of objections could be made out or explanations suggested about the correlations of the tests among themselves. But their correlation with the estimates cannot possibly be explained in any other way than by genuine perseveration." This generalization seems rather sweeping in view of the fact that the estimates themselves were admittedly not accurate measures of genuine perseveration, nor probably of anything genuine, in view of their low reliability.

Bernstein was concerned primarily with the problem of the existence

of a speed factor, his investigation of perseveration being somewhat incidental. In this study of speed 5 types of performance were given to the two groups of subjects described above. Bernstein's tests were sentence completion, directions, concomitants (similarities and differences), moral classification, and analogies. These 5 tests were given in 10 series, each series consisting of 4 tests of each variety, administered at various rates, which presumably represented different levels of speed. Speed levels were denominated "very leisurely, rather leisurely, rather fast, very fast." Teachers' estimates of intelligence and of slowness were also secured, each of these traits being rated on a scale from 1 to 10. The reliability coefficients of these estimates made by two judges were for intelligence .81 (group 1) and .84 (group 2); for slowness .42 (group 1) and .55 (group 2). The reliability coefficients of the different forms of each test are reported and averaged. These averages range from .60 to .72, which, considering the number of times the tests were repeated, are not very high. Spearman, citing Bernstein's work, (*25*, p. 252) averages the tests at each speed in the two groups, and finding that neither the most hasty nor the most leisurely tests yield the highest r's with the intelligence estimate (which he seems to regard as a measure of g) concludes that "in principle at least, the characters of goodness and speed stand upon similar footings in respect of saturation with g". From this result and from the very low correlation between the estimates of slowness and the L–H[11] scores, Bernstein concludes that there is no general speed factor. There is a fairly obvious discrepancy between the actual data reported here and the broad generalization made by Bernstein and Spearman. The existence of a speed factor is still, then, an open question.

Carey, another student of Spearman, has investigated the existence of a memory factor in mental activities. Carey (*6*) worked with "about 150" subjects, consisting of 5 different classes of school children, ages 7 to 14, and including both boys and girls in unequal proportions. Correlation coefficients were computed between the tests for each class separately (there being about 30 subjects in each class) and then averaged to give final values.

Carey's tests included measures of verbal memory; sensory discrimination in visual and auditory modalities; sensory memory; imagery; as well as two tests of g, *viz.*, opposites and disarranged sentences. The reliability coefficients of the 10 memory and 7 discrimination tests ranged from .36 to .70. All of the intercorrelations were corrected for attenuation, corrections being very large in many cases in view of

[11] Pooled scores of all of the tests, obtained by finding the differences in score between the leisure and haste tests, and taken as a measure of slowness

the low reliabilities of the tests. Pools of the various tests were then made, all of the verbal memory tests, all of the visual discrimination tests, *etc.*, being taken together; but even the reliabilities of these pools were none too high, ranging from .53 to .81.

The final criterion which Carey employed to determine the presence of general, group, and specific factors was the correlation of the tests with g. These correlations were computed for the separate tests as well as for six pools of tests, the data being examined for the presence of two possible factors, a discrimination factor, and a memory factor. Carey believes there is no evidence for the first factor, since upon securing the intercorrelations of his three discrimination pools and partialing out g, the resulting correlations averaged .03, the highest being .07. In the case of the memory tests, however, the specific correlations (correlations with g partialed out) between the 3 memory pools are $.27 \pm .05$; $.19 \pm .05$; and $.13 \pm .05$. Generalizing on the basis of these quite unreliable results, Carey concludes that there is in addition to Spearman's g a small memory factor running through his tests. Even if these data were not subject to errors of sampling and measurement, this conclusion would still be dubious for the following reasons: (1) Carey did *not* prove the presence of a general factor through his tests in the first place, and hence was not justified in computing correlations with it (*i. e.*, r_{ag}'s); (2) Spearman's r_{ag} formula assumes in its derivation the absence of group factors, and therefore cannot be used as a means of discovering their presence. Carey's memory factor, therefore, is probably an artifact growing out of his method, rather than a true ability.

In 1915 an extensive investigation of character by means of the rating technique was undertaken by Webb (*31*), whose results, according to Spearman (*25*, p. 345), "stand up to the present time without rival." Commenting further upon the significance of Webb's findings, Spearman writes (*16*): "He . . . found that human character, and especially the differences between individuals has one paramount character, namely the degree to which conduct is controlled by present impulse."

Webb worked principally with two groups of college students, the first group consisting of 98, and the second of 96 subjects, all men, the average age being 21 years. These students were rated upon each of 39 complex character traits by 10 prefects,—fellow students acting as monitors, and in charge of routine discipline. Ratings were made on a 7-point scale, the judges being paired so that about 20 students were assigned to each pair of judges. The reliability coefficients of

these ratings were very low, averaging only .55, even when those which fell below the arbitrary limit of .31 were discarded. Corrections for attenuation were, accordingly, large, several corrected r's being greater than 1 00,—a rather curious result.

In addition to the ratings, tests of Opposites and Disarranged Sentences were given to the 98 subjects in Group I, and tests of Opposites, Definitions, Practical Problems, Comparisons, and Reasoning to the 96 men in Group II. These tests, which seem to be largely measures of verbal or linguistic abilities, were considered to be measures of Spearman's g. The reliabilities of the last 5 of these tests ranged from .65 to .81, with a mean at .73.

The complexity and broad extent of Webb's character traits can best be shown by several illustrations: Tendency to do kindness on principle; intensity of influence upon associates; strength of will; degree to which he works with distant objects in view; pure-mindedness. It is obvious that the employment of a large number of very general attributes upon which individuals are to be rated on a rather narrow scale will serve greatly to enhance the "halo" effect. Such "halo" effect was even more emphasized, perhaps, by having each prefect submit, besides, a general character sketch of the subjects whom he rated *before* he made his specific ratings. It seems quite probable that high correlations among such ratings reflect a general factor in the raters rather than in the subjects rated. Rugg's illuminating study of ratings (*22*) has shown clearly the extent to which unrecognized bias can affect one's judgment, even under the best conditions of motivation.

It must be remembered that the prefects were of almost the same age and of much the same education and (presumably) social background, so that their views and attitudes must have been closely similar. Hence if one regarded a well-liked, gentlemanly fellow, a good—but not too good—student as possessing profoundness, originality will-power, tact, *etc.*, it is very likely that another prefect would also so regard him. Disagreement among prefects as to traits, shown in the low reliability of a rating, would be largely offset by the correspondingly large correction for attenuation.

Another common element, which undoubtedly ran through Webb's list, arises from the vagueness inherent in such descriptions as conscientiousness, quickness of apprehension, tendency to quick oscillation between cheerfulness and depression, *etc.* Such traits must be rated very "generally" because they are general. If estimates of probable behavior under specific conditions, *e. g.*, in the class room, at social functions, at sports, *etc.*, had been called for, the validity of the ratings

made by Webb's judges would certainly have been increased (*18*). Still another objection to the use of such broad descriptive traits has been made by Kelley on the score of the impossibility of defining them accurately enough for verification. Apropos Garnett's work on Webb's data, he writes (*15*, p. 5): "Still more serious is the fact that it is incapable of verification, for we cannot duplicate by reproduction of the investigation, step by step, our own interpretation of Garnett's interpretation of Webb's judges' interpretation of the traits of these unknown subjects."

Using the older intercolumnar correlation criterion, Webb found evidence of the presence of a general factor in eight of his character estimates. This factor he defined as "consistency of action resulting from deliberate volition or will" (*31*, p. 60) and denoted by the letter "*w*". The attempt was then made to establish the independence of this factor from Spearman's *g* by partialing out the pool of intelligence tests from the intercorrelations of the character estimates. This could hardly be termed a successful elimination of *g*, however, as most of the correlations of pool and estimates were very low in the first place, the average being only .20. If a set of estimates has low intercorrelations with a battery of verbal tests, obviously partialing out the latter will have little effect upon the correlations of the estimates *inter se*. All in all, it seems to the writers that "*w*," as determined by Webb, is a decidedly hypothetical character factor.

Other general factors, *viz.*, cleverness and oscillation, have been put forward as traits by Spearman and his group. Space does not permit us to review the experimental data upon which these factors are based. We feel, however, that they are not securely established and should be verified. It is unfortunate that it has been necessary for us to be critical rather than commendatory of the studies cited in Part II. That they contain much of value, we heartily agree. But our task has been the thankless one of pointing out errors of technique in order to prevent, if possible, their reoccurrence, rather than of dealing in vague and meaningless approbation.

APPENDIX 1

Let
$$t_{1234} = r_{12}r_{34} - r_{13}r_{24}$$

To correct for attenuation, divide both sides of this equation by $\sqrt{r_{1I}\, r_{2II}\, r_{3III}\, r_{4IV}}$. Call the corrected t, t'; and the corrected r's, R. We then have

$$t'_{1234} = R_{12}R_{34} - R_{13}R_{24}$$

$$t'_{1234} + \Delta_{1234} = (R_{12} + \Delta_{12})\,(R_{34} + \Delta_{34}) - (R_{13} + \Delta_{13})\,(R_{24} + \Delta_{24})$$

Expanding, subtracting t'_{1234} from each side, and neglecting second degree terms in the Δ's, since they are of an order $1/\sqrt{N}$ to the first degree terms, and hence small if N is large, we have

$$\Delta_{1234} = \Delta_{12}R_{34} + \Delta_{34}R_{12} - \Delta_{13}R_{24} - \Delta_{24}R_{13}$$

Squaring, summing, and dividing by N we have

$$\sigma^{2}_{t'1234} = \sigma^2_{R12}R^2_{34} + \sigma^2_{R34}R^2_{12} + \sigma^2_{R13}R^2_{24} + \sigma^2_{R24}R^2_{13} + 2(\sigma_{R12}R_{34}\sigma_{R34} R_{12}r_{R12R34} + \sigma_{R13}R_{24}\sigma_{R24}R_{13}r_{R13R24} - \sigma_{R12}R_{34}\sigma_{R13}R_{24}r_{R12R13} - \sigma_{R12}R_{34}\sigma_{R24}R_{13}r_{R12R24} - \sigma_{R34}R_{12}\sigma_{R13}R_{24}r_{R13R34} - \sigma_{R34}R_{12}\sigma_{R24} R_{13}r_{R34R24})$$

The σ_R's can be evaluated by formula (*161*) in Kelley's *Statistical Method* for the *S. E.* of a coefficient of correlation corrected for attenuation by the formula $r_{\infty\infty} = \dfrac{r_{12}}{\sqrt{r_{1I}\, r_{2II}}}$, *i.e.*,

$$\sigma_{r_{\infty\infty}} = \frac{r_{\infty\infty}}{\sqrt{N}}\left(r^2_{\infty\infty} + \frac{1}{r^2_{12}} + A_{1I} + A_{2II}\right)^{1/2}$$

This formula in our notation becomes

$$\sigma_{R_{12}} = \frac{R_{12}}{\sqrt{N}}\left(R^2_{12} + \frac{1}{r^2_{12}} + A_{1I} + A_{2II}\right)^{1/2}$$

The quantities $1/r_{12}$ and A_{1I}, A_{2II} (which take their values from r_{1I} and r_{2II}) are tabled for different values of r in Table XL, Kelley's *Statistical Method*, p. 211. There are four σ_R's which may be written more briefly by representing the right hand parenthesis as follows:

$$\text{Let } A = \left(R^2_{12} + \frac{1}{r^2_{12}} + A_{1\text{I}} + A_{2\text{II}}\right)^{\frac{1}{2}}$$

$$B = \left(R^2_{13} + \frac{1}{r^2_{13}} + A_{1\text{I}} + A_{3\text{III}}\right)^{\frac{1}{2}}$$

$$C = \left(R^2_{24} + \frac{1}{r^2_{24}} + A_{2\text{II}} + A_{4\text{IV}}\right)^{\frac{1}{2}}$$

$$D = \left(R^2_{34} + \frac{1}{r^2_{34}} + A_{3\text{III}} + A_{4\text{IV}}\right)^{\frac{1}{2}}$$

The terms involving the correlation between correlation coefficients have been expanded by the formulas given by Pearson and' Filon (*Phil. Trans.* 1898, Vol. 191*A*, pp. 259, 262). We have put $r_{R12\,R34} = r_{r_{12}r_{34}}$ and $r_{R12R13} = r_{r_{12}r_{13}}$, *etc.*, on the assumption that the reliability coefficients enter as constant multipliers in the two correlated series, *e. g.*, r_{12}, r_{34}, and hence do not affect the correlation. This will be true if the samples successively drawn are of approximately the same size and variability, so that $r_{1\text{I}}$, $r_{2\text{II}}$, $r_{3\text{III}}$, $r_{4\text{IV}}$ do not change greatly from sample to sample.

In the final formula the term $\sqrt{r_{1\text{I}} \cdot r_{2\text{II}} \cdot r_{3\text{III}} \cdot r_{4\text{IV}}}$ is factored out as V, *i. e.*,

$$V = \sqrt{r_{1\text{I}} \cdot r_{2\text{II}} \cdot r_{3\text{III}} \cdot r_{4\text{IV}}}$$

For uniformity all correlations are put in the form of the uncorrected or original r's.

Making the substitutions indicated, we have, finally

$$PE_{t'1234} = \frac{.6745}{V\sqrt{N}} \Bigg[r^2_{12}r^2_{34}(A^2 + D^2) + r^2_{13}r^2_{24}(B^2 + C^2) + \frac{ADr^2_{12}r^2_{34}}{k^2_{12}k^2_{34}}$$

$$\Big(2r_{13}r_{24} + 2r_{14}r_{23} - 2r_{12}r_{23}r_{24} - 2r_{13}r_{23}r_{34} - 2r_{12}r_{13}r_{14}$$

$$- 2r_{14}r_{24}r_{34} + r_{12}r_{34}\{r^2_{13} + r^2_{14} + r^2_{23} + r^2_{24}\}\Big) + \frac{BCr^2_{13}r^2_{24}}{k^2_{13}k^2_{24}}\Big(2r_{12}r_{34}$$

$$+ 2r_{14}r_{23} - 2r_{12}r_{23}r_{24} - 2r_{13}r_{23}r_{34} - 2r_{12}r_{13}r_{14} - 2r_{14}r_{24}r_{34}$$

$$+ r_{13}r_{24}\{r^2_{12} + r^2_{23} + r^2_{14} + r^2_{34}\}\Big) - 2r_{12}r_{13}r_{24}r_{34}$$

$$\Big(ABr_{23} - \frac{ABr_{12}r_{13}\{k^2_{23} - r^2_{12} - r^2_{13} + 2\,r_{12}r_{13}r_{23}\}}{2\,k^2_{12}k^2_{13}}$$

$$+ ACr_{14} - \frac{ACr_{12}r_{24}\{k^2_{14} - r^2_{12} - r^2_{24} + 2r_{12}r_{14}r_{24}\}}{2\,k^2_{12}k^2_{24}}$$

$$+ BDr_{14} - \frac{BDr_{13}r_{34}\{k^2_{14} - r^2_{13} - r^2_{34} + 2r_{13}r_{14}r_{34}\}}{2\,k^2_{13}k^2_{34}}$$

$$+ CDr_{23} - \frac{CDr_{24}r_{34}\{k^2_{23} - r^2_{24} - r^2_{34} + 2r_{23}r_{24}r_{34}\}}{2\,k^2_{24}k^2_{34}}\Big)\Bigg]^{1/2}$$

This formula is long and rather unwieldy. However, the A, B, C, and D which should be calculated at the outset, are often repeated, as are many of the r–products; and with the aid of tables and a calculating machine, a $PE_{t'}$ may be computed in approximately one–half hour.

BIBLIOGRAPHY

BERNSTEIN, E.
(1) 1924. Quickness and Intelligence, British Journal of Psychology, Mono. No. 7, pp. 55.

BONSER, F. G.
(2) 1910. The Reasoning Ability of Children, Teachers College, Columbia University Contributions to Education, No. 37, pp. 133.

BRIGHAM, C. C.
(3) 1930. Intelligence Tests of Immigrant Groups, Psychological Review, XXXVII, pp. 158–165.

BROWN, W., and THOMSON, G.
(4) 1921. Essentials of Mental Measurement.

BRUNT, DAVID.
(5) 1923. The Combination of Observations.

CAREY, N.
(6) 1915–17. Factors in the Mental Processes of Schoolchildren. British Journal of Psychology, VIII, pp. 70–92.

CAROTHERS, F. E.
(7) 1921. Psychological Examination of College Students, Archives of Psychology, XLVI, pp. 82.

CURETON, E. E., and DUNLAP, J. W.
(8) 1930. Spearman's Correction for Attenuation and its Probable Error. American Journal of Psychology, XLII, pp. 235–245.

CURETON, E. E., and DUNLAP, J. W.
(9) 1930. Some Effects of Heterogeneity on the Theory of Factors, American Journal of Psychology, XLII, pp. 608–620.

EZEKIEL, M.
(10) 1930. Methods of Correlational Analysis.

FISHER, R. A.
(11) 1928. Statistical Methods for Research Workers.

HOLZINGER, K. J.
(12) 1930. Statistical Resume of the Spearman Two-Factor Theory.

HULL, C. L.
(13) 1928. Aptitude Testing.

KELLEY, T. L.
(14) 1923. Statistical Method.

KELLEY, T. L.
(15) 1928. Crossroads in the Mind of Man.

LANKES, W.
(16) 1915. Perseveration, British Journal of Psychology, VII, pp. 387–419.

MAY, MARK
(17) 1929. A Method for Correcting Coefficients of Correlation for Heterogeneity in the Data, Journal of Educational Psychology, XX, No. 6, pp. 417–423.

MAY, MARK, and HARTSHORNE, HUGH
(18) 1928. Studies in Deceit.

PEARSON, KARL
(19) 1896–1897. Mathematical Contributions to the Theory of Evolution. On a Form of Spurious Correlation which May Arise when Indices are Used in the Measurement of Organs, Proceedings of the Royal Society, LX, pp. 489–498.

PEARSON, K., and MOUL, M.
(20) 1927. The Mathematics of Intelligence. I. The Sampling Errors in the Theory of a Generalized Factor, Biometrika, XIX, pp. 246–291.

PIAGGIO, H. T. H.
(21) 1931. The General Factor in Spearman's Theory of Intelligence, Nature, Jan. 10, CXXVII, No. 3193, p. 56.

RUGG, H. O.
(22) 1921–1922. Is the Rating of Human Character Practicable? Journal of Educational Psychology, XII–XIII, pp. 425–501, 30–93.

SIMPSON, B. R.
(*23*) 1912. Correlations of Mental Abilities, Teachers College, Columbia University, Contributions to Education, No. 53, pp. 122.
SPEARMAN, C.
(*24*) 1907. Demonstration of Formulæ for True Measurement of Correlation, American Journal of Psychology, XVIII, pp. 161–169.
SPEARMAN, C.
(*25*) 1927. Abilities of Man.
SPEARMAN, C., and HART, B.
(*26*) 1912. General Ability, its Existence and Nature, British Journal of Psychology, V, pp. 51–84.
SPEARMAN, C., and HOLZINGER, K. J.
(*27*) 1924. The Sampling Error in the Theory of Two Factors, British Journal of Psychology, XV, pp. 17–19.
SPEARMAN, C., and HOLZINGER, K. J.
(*28*) 1930. The Average Value for the Probable Error of a Tetrad Difference, British Journal of Psychology, XX, pp. 368–370.
SYMPOSIUM, INTELLIGENCE AND ITS MEASUREMENT.
(*29*) 1921. Journal of Educational Psychology, XII, pp. 123–147 and 195–216.
THORNDIKE, E. L.
(*30*) 1924. A Communication and a Reply, Journal of Educational Psychology, XV, pp. 394–5.
WEBB, E.
(*31*) 1915. Character and Intelligence, British Journal of Psychology, Mono. No. 3, pp. 99.
WILSON, E. B.
(*32*) 1928. Review of Spearman's Abilities of Man, Science, LXVII, No. 1731, pp. 244–248.
WISHART, JOHN
(*33*) 1928. Sampling Errors in the Theory of Two Factors, British Journal of Psychology, XIX, Part II, pp. 181–187.

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